A SYSTEMS ANALYSIS FOR MANAGERIAL STUDY OF COW-CALF PRODUCTION

By

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To

the memories of my father, Mogonodjial,

and my brother, Bekamgoto.

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Major Department: Animal Science

A mathematical model of a cow-calf production system, suitable to North Florida conditions, was built and converted into a Fortran based computer program for managerial study of cow-calf production. The program, called UF COW-CALF, simulates herd dynamics, growth and development of an average animal. Individual productive performance and nutritional requirements, based on sex, age, breed, physiological state, and nutritional and environmental conditions, were scaled to the herd level according to the size of each functional and age class.

The effects of breed and culling policy on net return were studied in the test application of UF COW-CALF. Light and heavy cullings with Brangus and Angus breeds were considered. Old cows and those with a dead calf at

parturition were removed under both culling policies. Cows open following a breeding season were removed under heavy culling. Only cows open in two consecutive breeding seasons were eliminated under light culling. Culled cows were replaced with available weaned heifers. No reproductive improvement within breed was expected. Experimental data used reflected breed adaptation to North Florida conditions.

The results were accurate and comparable to those of previous studies. Light culling caused higher percentages of growing and mature cows to alternate cyclically. Twenty-seven percent more calves were sold under light than heavy cullings. Fifty-eight percent more cows were culled under heavy than light cullings. Average annual production cost under heavy culling exceeded that for light culling by 6 percent.

Brangus cattle grew faster and had higher nutritional requirements than Angus cattle. Average annual production cost with Brangus cattle exceeded that with Angus cattle by 13 percent. Combining Brangus cattle with heavy culling was the most expensive strategy, but generated higher net return than raising Angus breed with either of the two culling policies. Combination of Brangus breed with light culling was the most profitable practice.

In conclusion, UF COW-CALF was considered a valid tool for managerial study, light culling was favored over heavy culling without reproductive improvement, and Brangus cattle were more suitable for North Florida than Angus cattle.

CHAPTER I
INTRODUCTION

Brief History of the Florida Beef Cattle Industry

Until three decades ago, the scrub cattle raised in the harsh climate and poor pastures of Florida were slaughtered mainly for local consumption and did not produce high quality meat (Florida Department of Agriculture and Consumer Services, 1977; Shonkwiler and Spreen, 1983). The situation changed rapidly in the following years (Koger et al., 1961). The realization that cattle could be a source of substantial income prompted the development of techniques for disease control, improvement of pastures and breeding, and the adoption of improved feeding and management practices. Consequently the Florida beef cattle industry became increasingly important, as evidenced by the numbers and sales of cattle recorded by various agencies and shown in Table 1-1.

Most of Florida cattlemen adopted the practice of improving pasture in order to increase productivity as the native grazing land was generally unsuitable for profitable commercial operations. Koger et al. (1961) reported that by 1961 more than 2 million out of 15 million acres of flatwood

soils in Florida were improved by fertilization, application of new grazing practices, and introduction of exotic grasses such as Star (Cynodon plectostachyus, Pilger), Bahia (Paspalum notatus), Bermuda (Cynodon dactylon), etc. In 1977, approximately 16 years later, the Florida Department of Agriculture and Consumer Services recorded three million acres of improved pastures in Florida.

Extensive and intensive cattle production systems were practiced on native and improved pasture, respectively. The extensive system consists of large herds of breeding animals grazing on large areas of rangeland; a farm herd with fewer animals on smaller, usually improved pastures, constitutes the basis for an intensive production system (Florida Department of Agriculture and Consumer Services, 1977).

The work of improving pastures was undertaken in parallel with the genetic improvement of the cattle population (Florida Department of Agriculture and Consumer Services, 1977). Native scrub cows, already adapted to the harsh range conditions, were systematically selected and mated to purebred Brahman and British bulls to produce offspring of improved breeding and higher market quality. The introduction of both the Brahman and British breeds in Florida was made possible by its unique geographic location where tropical and temperate climates overlap.

Purebred, cow-calf and feedlot operations are the main enterprises of the Florida beef cattle industry. However, the cow-calf operation is predominant and is based on grass as the main source of feed. Forage is more suitable for cow-calf operations since it can be produced relatively cheaply in most of the state almost year-round because of mild winters and abundant rainfall. For instance, Koger et al. (1961) reported temperature minima of -3.33° C to 9.44° C and average rainfall of 1313 mm per year over a seven-year period at the Beef Research Unit of the University of Florida. This station is located in the northern part of Florida.

Problems of the Florida Beef Cattle Industry

The combination of conditions described above and the lack of locally produced high energy feeds explain the outshipment of Florida raised cattle to other states for finishing. In 1980, calves accounted for 85 to 90 percent of the outshipments while cows and yearling feeder cattle constituted 10 to 15 percent (Simpson and Baker, 1980). Florida crossbred cattle are generally more resistant to heat and humidity and thus are among the breeds preferred by feedlots in Texas, Arizona, and Oklahoma (Shonkwiler and Spreen, 1983).

Due to the energy crisis in recent years, serious efforts have been made to finish Florida cattle in Florida in order to eliminate high costs of shipment by truck to distant feedlots. These efforts translated into rising numbers of slaughtering establishments with growing problems of feed supply. Meat packing plants more than doubled in number from 1961 to 1980 according to United States Department of Agriculture records (1955-1980). Unfortunately, beef prices in Florida have declined steadily for the last four years, causing stagnation, even a decrease, in the number of cattle raised and forcing the closure of some meat packing plants. The Florida beef cattle industry, as described above, is a reminder of the growing number of farm land ownership foreclosures in the United States that have raised the awareness of agricultural scientists to the economic plight of American farmers. Their predicament is the result of the vagaries of weather and the increasing complexity of the world market, two factors that they cannot control.

Formulation of a Strategy for Assisting the Florida Beef Cattle Industry

The present research addresses factors controllable at the farm level. Understanding and careful monitoring of these factors could lead to satisfactory economic efficiency of production. For instance, farmers have some control over

production costs. In the beef cattle industry, feeding animals is the major component of production expenses and is considered in this dissertation. In order to estimate cost of feeding, it is necessary to determine nutrient requirements for a specified level of performance of production activities, especially growth and development, lactation and reproduction. Information about nutrient requirements must be translated into actual amounts of feed, and ultimately into cost of feeding.

Many management tools in animal husbandry are related to controllable factors affecting nutritional requirements. For example, feed type, implying feed quality, and feed availability must be among the first considerations of a beef cattle producer. Choice of breeding season to match periods of abundant feed with periods of high feed demand by the herd is also an available management option. Age, sex and breed affect nutritional requirements through their corresponding effects on growth and development, lactation and reproduction. Feed demand and cost vary with herd size and structure, two attributes that are controllable through culling policy. Backgrounding of weaned calves prior to sale is practiced by some producers. The latter assume that higher returns expected for late sale of feeder calves will offset the cost of prolonged feeding.

The main objective of the research reported in this dissertation was to develop a tool for predicting the nutritional requirements, in terms of energy and protein, for growth and reproduction of a beef cattle herd under Florida conditions. This tool should be flexible enough to account for the wide range of potential management practices, as combinations of elements of management mentioned above. It was believed that systems analysis could be the tool. Consequently, a model of a cow-calf production system was built, which was implemented on a digital computer in order to meet to the main objective.

System analysts study the behavior of production systems and establish quantitative relationships existing among their components. Those relationships are used to build mathematical models, i.e., abstractions of the empirical world, in forms that permit the study of properties of systems of interest. Mathematical models are primarily used to explore categories of important questions. Answers to these questions, formulated as hypotheses, constitute the basis for experimental studies. The results of such studies are often considered in testing the consistency of those hypotheses. In systems analysis, mathematical models are converted into computer programs to

facilitate behavior analysis, or simulation of the system under study.

Historically, systems analysis has its origin in non-agricultural fields as a result of emphasis on industrial development, and especially the development of the arms industry during the two world wars. Due to the allocation of huge financial and human resources to this goal, substantial progress was made in understanding the behavior of physical systems, and reproducing it under specified conditions, even prior to the invention of computers. There was no real motivation to apply systems analysis methodology to the agricultural sector 50 years ago.

Recently, there has been growing pressure and need for the United States agricultural industry to produce more efficiently. This situation and rapid developments in computer science gave interested scientists the incentive to apply systems analysis to the study of biological processes. Less success has been recorded in this case as it requires more time and also because of the diverse and variable nature of the biological world. However, many difficult problems posed by the stochastic nature of agricultural systems have been successfully addressed during the last decade (Jones, 1982). Solutions to complex systems of equations related to biological systems, previously

insoluble by hand, are now allowed by modern computer technology. Simulation models of crop systems, such as the Florida Crop and Pest models (Mishoe et al., 1984), and livestock systems, such as the Kentucky Beef-Forage model (Loewer and Smith, 1986), are significant achievements in the application of systems analysis methodology to improving efficiency of agricultural production. Since more agricultural engineers, mathematicians and biologists are becoming involved in this effort and working in interdisciplinary research teams, rapid progress should be expected in the near future.

Objectives and Organization of the Study

This dissertation is a continuation of efforts undertaken by biological systems analysts. Its basic concern was the application of systems analysis to the study of beef cattle production, particularly cow-calf operations in Florida. The focus was on herd dynamics, growth and nutrition, and management, with the main goal being the development of a model for determining net energy and crude protein required for a relatively satisfactory level of reproduction and growth performance by an entire herd under various management conditions. More specifically, the objectives of the research were the following:

1. To define and conceptually model a cow-calf production system, including herd population dynamics, growth and development, lactation and reproduction, and various management options available in Florida;

2. To develop a mathematical model corresponding to the conceptual model developed under item 1;

3. To convert the mathematical model into a Fortran based program for simulation of a cow-calf production system under alternative management practices;

4. To perform a preliminary validation of the model using experimental data generated by the Beef Research Unit (BRU) of the University of Florida; and

5. To use the simulation program to study alternative management schemes for a cow-calf operation in Florida, taking into consideration the effects of the following factors on nutritional requirements, herd size and composition, and net returns:

(a) breeds and crosses,

(b) culling policies: culling cows open for the first time versus culling cows open for two consecutive breeding seasons.

Table 1-1. THE INCREASING IMPORTANCE OF FLORIDA BEEF CATTLE INDUSTRY IN TERMS OF BEEF CATTLE NUMBERS AND SALES.

Year	Numbers of Cattle	Sales
	1,000 head	1,000 dollars
1929	355	3,560
1939	623	3,589
1949	926	22,245
1959	1,294	73,129
1964	1,610	77,000
1969	1,698	NA
1973	1,977	223,376
1974	2,490	140,313
1975	2,920	185,639
1976	2,950	208,877
1977	2,800	276,873
1978	2,350	357,850
1979	2,180	423,721
1980	2,300	347,706
1981	2,480	371,764
1982	2,350	846,000
1983	2,425	909,375
1984	2,330	850,450

SOURCE: Florida Department of Agriculture and Consumer Services, 1977.
SOURCE: Florida Crop and Livestock Reporting Service, 1981.
SOURCE: Florida Crop and Livestock Reporting Service, 1984.

NA: not available.

CHAPTER II
LITERATURE REVIEW

The purpose of Chapter II is to review existing knowledge about the biological phenomena and their mathematical descriptions which provide the basis for the present study. Specific areas of interest are physiological processes such as growth, reproduction and milk production, and the nutritional factors accompanying them. Other areas of interest are herd population dynamics and herd management. There is an attempt to point out relevant genetic aspects. Application of knowledge in these areas to previous analyses of cattle production systems are discussed.

This chapter is presented in six sections.

- Population dynamics
- Growth and development, lactation and reproduction
- Nutritional requirements for growth, maintenance, lactation and reproduction
- Systems analysis, modeling and simulation
- Beef cattle management studies
- Beef cattle production models

Population Dynamics

Population dynamics is an area of biology that attracts many systems analysts. It involves growth and development, reproduction, mortality and migration as factors contributing to the fluctuation in size and structure of a population. Reproduction, as the major process of population growth, has attracted many researchers and led to the diversity of published population models (Feller, 1941; Pielou, 1969; Lewis, 1972). A few illustrative cases are discussed below.

Brody (1945) found a general similarity between the growth of individuals and populations: both are sigmoid as shown in Figure 2-1. His explanation of this phenomenon was that our bodies are made of a population of cells, and our bodies, in turn, are cells of the social body. According to Brody, curves of both population and body weight have an accelerating phase (phase one), a decelerating phase (phase two), and an inflection point. The inflection point occurs where the reproductive rate declines or the excess population migrates as consequences of environmental back pressure. Brody expressed population growth in the following manner:

$$\frac{dN}{dt} = K_1 N_t \qquad \text{in phase one and}$$

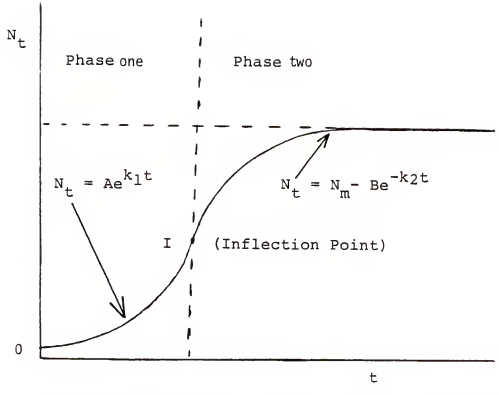


Figure 2-1. Typical graph of population growth as depicted by Brody (1945).

Refer to text for explanation of symbols.

$$\frac{dN}{dt} = K_2(N_m - N_t) \qquad \text{in phase two,}$$

where dn/dt is the continuous rate of change in population size, N_t represents the population size at time t; N_m is the maximum population and K_1 and K_2 are the acceleration rates of the population in phases one and two, respectively.

Researchers such as Lewis (1976) and Smerage (1983) were not only interested in the dynamics of a population but also in its structure. Lewis (1976) applied the theory of discrete and continuous networks, commonly used in the study of electrical systems, to single species population models. To illustrate his approach, he chose to discuss a population of identical protozoans that reproduce by binary fission and require no conjugation. He assumed a culture medium regulated to allow a constant interval between successive fissions. Death is a non-selective Poisson process with the probability of survival of an individual over any interval T_F, being given by e^{-mT}. A network embodying the dynamics of such a process is shown in Figure 2-3, where J_1 is the flow of newly formed fission products into the population and J_o is the flow of surviving adults into fission. Lack (1954), Clark et al. (1967), Bent (1968) and Sadleir (1973) used structures of the type described in Figure 2-2, for various animal species.

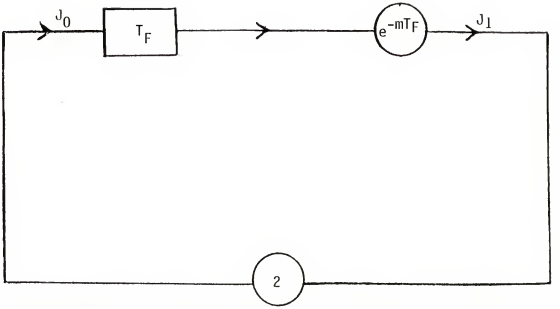


Figure 2-2. Network model for a binary fission in a population of identical protozoan.

T_F represents the time interval between fissions. J_0 is the flow of newly formed fission products into the population. J_1 is the flow of surviving individuals into fission. Death is a non-selective Poisson process, with the probability of survival of an individual given by e^{-mT_F}. The scale factor 2 indicates that two daughter cells emerge from each surviving individual that proceeds into fission.

While Lack (1954), Clark et al. (1967), Bent (1968) Sadleir (1973), Lewis (1976), and Athans et al. (1974) advocated the application of network theory to the study of populations, Smerage (1983) emphasized the fact that populations are systems distributed by age class in a physical space. He described a single-species age distributed population by its age classes. The latter were defined by their size N, assumed very large, age-space density n, and the flow F from one class to another. These variables describe the dynamics of the population as a consequence of inherent reproductive, death-related, developmental and migratory processes operating in concert.

Figure 2-3 is a representation of an animal species and its physiological processes (growth and development, reproduction, and death). It is an attempt to emphasize that biological systems are process-oriented entities and to focus on causal mechanisms which constitute the essence of their compositions and therefore govern their behavior. A two-stage life cycle is described. Individuals are born by process H_r into store C_1, where they begin the first stage of their life cycle. Store C_1 is characterized by population size N_1, flow F_1, density n_1, and area A_1. Individuals from store C_1 develop into members of store C_2

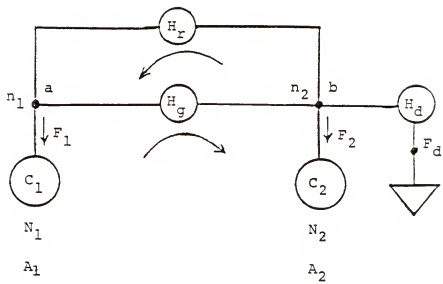


Figure 2-3. Dynamic processes of a single species animal population with a two-stage life cycle.

Individuals are born by reproduction process H_r into store C_1, characterized by population size N_1, flow F_1, density n_1 and area A_1. Individuals of C_1 develop into individuals of store C_2 by transformation H_g. Transformation H_g is species, age and environment dependent. Individuals of C_2 produce individuals of store C_1 by process H_r.

according to species, age and environment dependent tranformation H_g. Individuals in C_2 produce individuals in C_1 by process H_r. Physiological death or process H_d removes members of C_2 and transfers them to the population sink at density zero where they no longer participate in population processes.

Other models describing populations with different conceptual approaches may be found in the literature. However, the three examples discussed above are sufficient to outline the scope of population modeling considered in this dissertation. It is particularly important to emphasize that a model describing a population as a system distributed by age classes in a physical space is most appropriate for the study of dynamics and structure of a cattle herd. This model includes the notion of population density which alludes to stocking rate, a very important factor in cattle production systems. The notion of distribution of a population by age classes is also applicable to beef cattle husbandry where it is a good management practice to separate mature cows from heifers as the latter require particular attention.

Growth and Development, Lactation and Reproduction

Growth and development, lactation and reproduction are major biological processes of a beef cattle reproduction

system. A good understanding of these processes is prerequisite to the development of a meaningful model of such a system. Although substantial progress has been made in this direction by plant and animal physiologists, there remains much to be learned (Baker and Curry, 1976). Some relatively accepted explanations of growth processes, lactation and reproduction are discussed below.

Growth Process

Income of a commercial beef cattle production unit depends to a large extent upon size and live weight of animals available for sale (Peacock et al., 1966). Since size and weight are the products of the growth process, it is crucial to understand growth dynamics and to be aware of major factors influencing it. Growth results from physiological processes that cause one cell, the fertilized egg, to develop into many cells which grow in size. Hyperplasia and hypertrophy refer to growth in number of cells and growth in size of cells, respectively. These phenomena are under hormonal regulation and depend on availablility of necessary nutrients. Brody (1945), Menz and Knipscheer (1981) and Loewer et al. (1983) recognized that the rate of conversion of feed nutrients into growth materials is affected by a multitude of factors among which are the

quantity and quality of feed, climate and breed. Hypertrophied cells differentiate into specialized tissues of various organs of the animal. The total mass of body organs is referred to as body weight.

The above information results from the study of the mechanisms of animal growth by growth physiologists. Animal scientists, in general, are inclined to describe growth as a function of time, bearing in mind that it is the ultimate result of physiological processes varying with intrinsic animal factors such as sex and genotype, and a multitude of environmental factors including temperature and nutrient availability.

Brody (1945) described animal growth as a phenomenon occurring in two phases over time. During the first phase (phase 1), which lasts from conception to puberty, he asserted that animals grow at a rate relative to their actual weight. In the second phase (phase 2), which lasts from puberty to maturity, he observed that growth rate depends on total weight gain to be realized. The following mathematical expressions constitute Brody's animal growth model:

(2-1) $\frac{dW}{dt} = k_1 W_t$ in phase one and

(2-2) $\frac{dW}{dt} = k_2(W_m - W_t)$ in phase two,

where dw/dt is growth rate, k_1 and k_2 are relative growth rates in phases one and two, respectively, W_m is mature weight and W_t, weight at time t. The solutions to differential equations (2-1) and (2-2) are in the same order as follows:

(2-3) $W_t = A^{kt}$, t age at puberty in days and

(2-4) $W_t = Wm - B^{-kt}$, t age at puberty in days,

where A and B are constants of integration.

Other biologists have interpreted animal growth dynamics differently. Richards (1959) transformed equation (2-4) into the following expression:

(2-5) $W_t = Wm(1-Be^{kt})^M$

where W_t, W_m, B and t are as defined previously, M is a parameter which establishes degree of maturity at inflection point and k is the relative growth rate. The Bertalanffy equation (Bertalanffy, 1957) is a specific case of Richards' equation with M equal to 3:

(2-6) $W_t = Wm(1-Be^{-kt})^3$

The generalized form of the logistic function (Nelder, 1961) is as follows:

(2-7) $W_t = W_m(1+e^{-kt})^{-M}$

The Gompertz growth equation emphasizes that postnatal growth rate tends to undergo an exponential decay throughout its course as illustrated in the following expression (Laird, 1966):

(2-8) $W_t = W_o \text{ Exp}[\frac{A_o}{a}(1-\text{Exp}(-at))]$

where W_t is weight at time t, W_o is the initial weight, and A_o and (a) are constants. The initial specific growth rate and the rate of exponential decay of the specific growth rate are represented by A_o and (a), respectively.

Beef cattle producers also view growth as accumulation of body mass over time. For them, live weight is very important for estimating needed amount of feed and expected profit or loss, and for assessing the general health condition of the animal. They must therefore pay attention to their animals' growth as it progresses through time. Growth phases, such as preweaning growth and postweaning growth, and specific measures of growth, such as birth weight and weaning weight, are important indices of production for cattlemen.

Birth weight is influenced by numerous factors including sex of calf, age of dam, breed and time of calving

(Brown et al., 1972; Boyd, 1976). Lampo and Willen (1966) showed the effects of sex of calf and age of dam on calf birth weight. Restle et al. (1983), while analyzing the performance of Bos indicus (Brahman) and Bos taurus (Angus and Hereford) cattle and their crosses by generation at the Beef Research Unit, found that bull calves have heavier birth weights (29.9 kg) than heifers (28.1 kg). Restle et al., Reynolds et al. (1980), and many others have observed that birth weight increases with age of dam.

Lampo and Willen (1965) and Vaccaro and Dillard (1966) noted that heavier cows give birth to heavier calves. Nelson and Beavers (1982), Petty and Cartwright (1966), and Bellows et al. (1971, 1982) recognized the fact that breed affects birth weight. Petty and Cartwright reported birth weight heritability of 44 percent and its genetic correlation with yearling weight and mature weight to be 0.61 and 0.68, respectively. In other words, calves born to large size breeds will tend to have a heavier birth weight.

Preweaning growth is of particular interest to the cow-calf operator who sells his calves at weaning, since it affects operating cost and income. In general, preweaning growth is influenced by the maternal environment to which young animals are exposed before and after birth. Available data suggest that growth between birth and weaning is

genetically controlled. For instance, Andersen et al. (1974) reported that selection of replacement heifers on the basis of yearling weight increased daily gain of subsequent calves from birth to ten months of age. A study conducted by Brown et al. (1972) led to the conclusion that large gains at young ages are associated with early maturing females, while genotypes exhibiting sustained growth rate into advanced ages are associated with late maturing females. Late maturing females in the present context are females which, under optimal condition of feeding, reach mature weight at a later age. For example, a Brahman cow is a late maturing female in comparison to an Angus cow.

Brinks et al. (1961) and Leighton et al. (1982) reported higher growth rate for bulls than for heifers. Results of a study by Restle at al. (1983) indicated that heifers grew at the daily average rate of 0.83 kg, from birth to weaning, while the figure for steers from the same investigation was 0.90. Many other authors have reported similar findings.

Weaning weight is used in the selection of replacement heifers along with weaning conformation. It is affected by age of calf, season of birth, sire and feeding practices. Calves are weaned at the age of seven months on the average in the United States. Under normal conditions, calves lose

weight immediately following weaning, and it takes two to three weeks for them to regain their lost weight. The reason for the temporary decline in post-weaning weight is that calves cannot efficiently digest forage because of incomplete rumen development (McDowell, 1972). Stress of separation from the dam plays a major role in that weight loss. Peacock et al. (1976) considered systematic cross-breeding as a way to influence weaning weight as they reported that utilizing Brahman and Shorthorn breeds in this endeavor led to heavier weaned calves in South Central Florida. Crockett et al. (1973) made the same observation from the result of crossbreeding with the Brahman, Angus and Hereford breeds. Peacock et al. (1966), while working with Brahman, Hereford, Devon and Shorthorn cattle and their crosses raised in Florida, found that cows with one-half Brahman blood weaned the heaviest calves.

The beef cattle herd in the present model does not include the physical presence of bulls; however, one must still consider breeds and types of bulls which provide semen through natural service or artificial insemination. Knapp and Black (1941), Gregory et al. (1950) and Koger et al. (1951) agreed that breed of sire influences the weaning weight of calves. Leighton et al. (1982) stated that historically, weaning weight has been used as an indicator

of potential for rapid growth and a measure of maternal ability, both of which are important components of performance testing programs. These authors reported that environmental conditions in various regions of the United States have a significant effect on the weaning weight of Hereford cattle. The lowest weaning weight for this breed was recorded along the Gulf Coast.

After weaning, non-hereditary maternal influences become relatively less important than the individual's own genetic makeup, and may disappear completely at maturity. Although the maximum genetic size of an individual is fixed at conception, environmental factors, such as inadequate nutrition, disease and accidents, may prevent an individual from achieving its genetic potential (Campbell and Lasley, 1975). Mature size of farm animals is related to rate of gain from birth to market weight of feeder calves although other factors may be involved (Olson et al., 1982). In fact, the improvement of post-weaning growth is an important objective for animal breeders as well as feedlot operators. Manipulation of growth and carcass characteristics can be achieved by changing the genotype (Cundiff, 1970), nutrition or management practices (Morgan, 1979). Thompson et al. (1981) found that the growth advantage of crossbreds was mainly realized in periods of slow growth, corresponding to

late summer, autumn and winter months in Australia. Under those conditions, Brahman crosses grew 89 percent faster ($P<0.05$) than Hereford cattle. One can reasonably relate this result to feed availability and adaptability. Evidently these conditions did not constitute a natural habitat for Hereford animals.

A study by Peacock and Koger (1982) involving Angus, Brahman, Charolais cattle and their crosses fed for a fixed period of time showed that straightbred Charolais steers had the highest average daily gain. Peters et al. (1980) studied the performance of Africander, dual purpose breeds, specialized beef breeds and their crosses under extensive and intensive production conditions in subtropical environments. Analyses of their data tended to indicate that crossbred cattle had better growth performance in both systems. Deland et al. (1974) and Morgan et al. (1978) found no advantage for Bos indicus crosses in Mediterranean environment but Kennedy and Chirchir (1971) reported that crosses sired by the large European breeds grew faster than conventional Bos taurus cattle. All the above reports agree with Koger (1973), who stated that the most rapid method for achieving genetic adaptability and production characteristics is judicious crossbreeding of adapted and potentially productive breeds.

Another factor believed to influence growth performance is weight of dam. Correlations between cow weight and calf weight and gain indicate that heavier cows tend to produce heavier, faster gaining calves (Fitzhugh et al., 1967). Increase in cow weight during the suckling period was negatively correlated with calf weight and gain. The cows probably used available energy more for weight gain than for milk production.

Ferrell (1982) evaluated the effect of postweaning rate of gain of Angus, Hereford, Red Poll, Brown Swiss, Charolais and Simmental heifers on onset of puberty and productive performance. He observed that early puberty and weight at puberty are influenced by breed, rate of gain and the interaction between these two factors. In a related study, Stewart (1977) found that Angus and dairy breeds were earlier sexually maturing types and Brahman, a later maturing type; he also observed that animals heavier and taller as yearlings tend to be younger, heavier and taller at puberty. This phenomenon is largely due to the inclusion of dairy breeds in the study. Dow et al. (1982) studied the same phenomenon in Hereford, Red Poll x Hereford, Angus x Hereford, Angus x Charolais, Brahman x Hereford and Brahman x Angus x Hereford. They reported that weight and age at puberty were influenced by breed type and that Red Poll

heifers and their crosses were the youngest at puberty and Brahman crosses the oldest.

This section may be concluded by restating the remarks by Stobo et al. (1967), Klosterman et al. (1968), Broster et al. (1969) and Chigaru and Topps (1981) that birth weight, preweaning growth and cow weight fluctuate under the influences of nutritional regime, season, parturition, lactation, parasites and diseases. Furthermore, Chigaru and Topps observed that high producing cows lose weight in early lactation and gain during late lactation and the dry period.

Reproduction and Lactation

Reproduction involves natural or artificial insemination of sexually mature females, conception, gestation and parturition. It is a hormone regulated process. Rate of reproduction depends on the fertility of females and semen quality. Fertility rate is, in turn, influenced by factors which include age, breed and nutrition.

Good quality semen is recognized by a high proportion of motile and well shaped spermatozoa. Fields et al. (1982) found no difference in sperm concentration between Brahman and Angus bulls. Significant differences favoring Angus bulls were observed in rate of sperm forward movement, motility, total abnormality, and semen volume. Brahman

bulls also had less plasma testosterone. These facts may explain the lower reproductive rate of Bos indicus bulls in comparison to Bos taurus bulls observed by Koger et al. (1962), Chapman and England (1965), Gonzales-Padilla et al. (1969), Crockett al al. (1973) and Crockett et al. (1978). Nevertheless, when Bos indicus and Bos taurus bulls were raised together in an environment hostile to the latter, Bos indicus bulls tended to have higher fertility (Turner et al., 1968; Peacock et al., 1971, 1976, 1977a, 1977b). Lower fertility rate of Bos taurus bulls can be explained by impaired spermatogenesis as a consequence of incompatible environmental conditions.

Reproduction in sexually mature females starts with gametogenesis which is under hormonal regulation. Normally the ovary becomes functional at puberty, between the ages of 5 and 14 months in cattle. The development and activities of the ovary are associated with age, breed, nutritional regime, climate, health conditions, calving interval, parity, parturition and milk production (Plasse et al., 1970; Bindon et al., 1974; Benesova et al., 1974; Eulenberger et al., 1976; Suzuki et al., 1976; Grass et al., 1982; Bellows et al., 1982). Badinga et al. (1983) reported that fertility of cows was more sensitive to high

temperatures than heifers. In terms of age effect, Peacock et al. (1977a) reported that Brahman females have a low pregnancy rate at two years of age and tend not to rebreed as cows less than five years old while nursing a calf.

Milk production is an important component of mothering ability. Its effects on calf survival rate and weaning weight have been well recognized. Milk yield is affected by breed, age and plane of nutrition in the same manner as fertility, and more specifically by cow size and stage of lactation (Boyd, 1966; Chenette and Frahm, 1981). Dickey (1971), Rutledge et al. (1971) and Melton et al. (1967) reported a decline in milk yield as lactation progresses. Harville and Henderson (1964), Preston and Willis (1970) and many other researchers before and after them were convinced of the positive correlation between cow body size and milk production. This observation seems to be one logical explanation for the association of high progeny weaning weight with heavy cows reported by Vaccaro and Dillard (1966), Preston and Willis (1970) and Butts (1972).

The effects of health condition, calving interval, parturition and milk production on reproduction are not considered in the current modeling efforts. However, it would be advisable to include them in future developments.

Nutritional Requirements for Growth, Maintenance, Lactation and Reproduction

Nutrition is the underlying factor influencing growth, maintenance, lactation and reproduction in beef cattle production. This section is a brief review of studies related to the nutritional implications of growth and reproduction with emphasis on energy and protein requirements of these biological processes. There are also brief reports on previous studies involving dry matter intake and feed consumption.

Nutritionists have identified vitamins, protein, energy and some minerals as indispensable substances in biological processes. Nutrients should be present at the right time and in a proper combination to allow normal growth in higher animals, especially cattle. For instance, under nutrient deficiency during pregnancy, the mother draws on her body reserves to supply the needs of the developing fetus, but a prolonged deficiency will result in subnormal birth weight and reduced vigor. Many researchers, including Blockey et al. (1974), Lindsay (1976), Van Niekerk et al. (1968) and Maurer and Chenault (1983), have attributed embryo death and abortion to undernutrition of cows during pregnancy. Hafez (1968) mentioned that adequate nutrition during early pregnancy appears to be most critical for survival of a fetus; he reported that about two-thirds of total deaths

occur prior to the 25th day of gestation. Reid (1963) reviewed problems of adequate nutrition during the later part of pregnancy and noticed that prolonged maternal undernutrition effects on fetal size are most severe in that period.

Minerals and vitamins are essential for normal fetal development and growth, but quantity and quality of energy and protein are critical. Energy and protein can be measured in terms of their storage in fetal tissues (Hafez, 1968). Jacobsen et al. (1957) estimated that energy accumulates in the pregnant uterus in the following fashion:

$$V = 416e^{0.0174t}$$

where V stands for calories accumulated at time t in days after conception.

Moe and Tyrrell (1971) expressed the additional daily metabolizable energy (ME) required during pregnancy by the equation:

$$Y = (100.8 + 0.567e^{0.0174t})W^{0.75}$$

where Y is Kcal of ME per day, $W^{0.75}$ is the cow metabolic weight, and t, time in days. Brody (1945), Wilton et al. (1974), Ferrell et al. (1976), Boyd (1976), Sanders (1977) and Loewer et al. (1983) attempted to estimate energy

requirements for normal fetal growth and development during pregnancy. In general many researchers share the NRC (1976, 1978) view that additional energy should be provided to a pregnant cow during the last third of gestation only. Quantitative studies on protein requirements during pregnancy in cattle are scarce, even though researchers acknowledge its importance qualitatively. Blaxter and Rook (1953b) proposed the following relationship between calories and percent nitrogen deposited as a means of estimating protein requirement:

$$\text{Calories} = 9367 - 252.9 \times \% \text{ N}$$

where % N is percent nitrogen. The above expression is based on the assumption that deposits of fat and protein are not of a constant chemical composition. Jacobsen et al. (1957) indicated that the daily average protein deposition in the fetus the last 60 days prepartum could be calculated as

$$C = 1.136\ W^{0.70}$$

where C stands for grams of protein deposited in products of conception, and W is the pregnant cow weight.

There has been increasing evidence that both pre- and neonatal environments affect physical development and exert profound influence upon subsequent animal performance (Widdson and Dickerson, 1964). Studies by Waters (1908) and Sandibet and Verde (1976) showed that underfeeding may prolong the growth period without affecting ultimate size. Data published by Trowbridge et al. (1918) reinforce this proposition with the conclusion that an interval of restricted energy intake retards growth. However, by growing rapidly during subsequent periods of liberal feeding, animals are capable of recovering and reaching the same mature size as those which were well fed. This phenomenon is referred to as compensatory gain. Jacobson (1969) suggested that a 50 kg non-ruminating calf requires 47 Kcal per kg of body weight for maintenance, 3.3 Kcal per gram of body weight gain; a digestible protein requirement of 0.6 gram per kg of body weight corresponds to those energy levels. Stobo and Roy (1973) indicated that lower protein level would result in maximum efficiency of utilization of the dietary energy and protein when an all-concentrate diet was fed to fast growing calves. The studies of Carrol et al. (1964) also support the importance of the relationship between energy and protein requirement for a given rate of growth.

Preweaning growth is of concern to cow-calf producers whose objectives are for their sale calves to reach satisfactory weight and their replacement heifers and bulls to attain puberty at young ages. Protein requirements for growing and finishing cattle can be expressed as follows (Preston, 1966):

$$CP = 5.86\ W^{0.75}(1 + 0.924\ G)$$

where CP is crude protein required in grams, W is body weight in kg, and G, daily gain in kg.

In its effort to estimate protein requirements for growth, maintenance, lactation and pregnancy, the National Research Council adopted the factorial method developed by Mitchell (1929). In this method, the total crude protein required equals the sum of protein lost in urine, feces, and skin secretion plus protein deposited in weight gains of growing cattle and products of conception, plus the net protein required for synthesis of milk.

There have been many investigations of accurate methods for determining net energy requirements. Lofgreen and Garrett (1968) partitioned energy required for growing and finishing beef cattle into net energy for maintenance (NEm) and net energy for gain (NEg). Net energy for maintenance was expressed as follows:

$$NEm = 0.077\ W^{0.75}\ Mcal$$

for both males and females. Net energy for gain (NEg) is expressed by sex according to the following formulae:

$$NE_g = (52.75G + 6.84G^2)W^{0.75}\ Kcal \quad \text{for steers and}$$

$$NE_g = (56.03G + 12.65G^2)W^{0.75}\ Kcal \quad \text{for heifers,}$$

where G is kg of daily weight gain. Garrett et al. (1959) suggested that the net energy for maintenance and gain could be estimated according to the following expression:

$$NE_{m+g} = 35W^{0.75}(1 + 0.45G)$$

Van Demark and Mauger (1964), Almquist and Amann (1972), Bratton et al. (1959), Stewart (1977) and Ferrell (1982) demonstrated the association between plane of nutrition and earliness of sexual maturity in young growing cattle. Plane of nutrition is generally determined in terms of energy content of a diet. Researchers agree that animals on high planes of nutrition reach puberty at a younger age than those on low planes of nutrition. Bratton et al. (1961) reported age at sexual maturity of 38, 46 and 80 weeks for Holstein bulls on high, medium and low planes of nutrition, respectively. Animals reach puberty at relatively fixed weights within breeds. Holstein bulls on a

high plane of nutrition grew faster and therefore reached sexual maturity earlier than those on low and medium planes of nutrition.

Animals enter reproductive life at puberty. While they continue to grow, they require extra energy and protein for proper reproduction, i.e., cycling, gestation and lactation for females and soundness and vitality for males. Pendlum et al. (1977) observed a positive correlation between plane of nutrition and conception rate of heifers. Hill and Godley (1974) stated that a high postweaning plane of nutrition for heifers had a greater effect on reproductive performance than did preweaning gain.

Garrett's 1974 estimation of metabolizable energy (ME) for maintenance of Hereford cows was similar to that of Klosterman et al. (1968) for mature Charolais and Hereford cows, i.e., 112 Kcal of ME per kg of $W^{0.75}$. Neville and McCullough (1968) reported maintenance requirements for lactating and non-lactating Hereford cows of 178.4 Kcal and 137.4 Kcal of ME per kg of metabolic weight, respectively. Klosterman et al. indicated that maintenance requirements for mature cows are related to ration protein content, cow size and cow condition.

Lactation places a considerable stress on cows. Chigaru and Topps (1981) observed that cows underfed during

lactation tended not to achieve complete tissue repletion on refeeding. To prevent this condition, cows must be fed properly. Moe et al. (1972) recommended a NEm of 73 Kcal per kg of metabolic weight per day for a lactating cow in body energy equilibrium and ingesting a diet of optimum protein content under conditions of limited activity. The recommendation for milk production was 0.75 Mcal/day per kg of 4 percent fat corrected milk. Thomas (1971) reported higher milk yields by cows on high protein diets than for those on low protein diets. A dietary level of 10 percent crude protein appeared adequate for normal milk yield, i.e., 10 to 15 kg/day by dairy cows (Perkins, 1925; Moore, 1951; Lassiter et al., 1957; Perkins, 1957; Broster et al., 1960; Waite et al., 1968). A diet of 11.9 percent crude protein was not adequate for a dairy cow producing 22 kg of milk per day (Frens and Dijkstra, 1959).

Acquiring knowledge about nutrient requirements of beef cattle is the first step toward developing a comprehensive feeding practice. The second step is to provide animals with feedstuffs in appropriate quantity and quality for optimal growth, development and reproduction, based on estimated nutrient requirements.

Systems Analysis, Modeling and Simulation

Smerage (1981) wrote that early in the twentieth century, scientists began to realize that many seemingly disparate systems share common elements. The trend arose first in the physical sciences with the illumination of analogies between electrical, mechanical, fluid and thermal systems. The analogies drew the attention of engineers, physicists, biologists, chemists, physiologists, economists and sociologists. As a consequence, the investigation of the fundamental processes and mathematical characteristics of systems in various fields began resulting in the birth of systems analysis.

The term "system" is used in a wide variety of ways. Baker and Curry (1976) found it difficult to cover these ways in a single, concise and functional definition. However, the following definition by Halter and Miller (1976) reflects how a system is conceived in the present study. A system is an aggregate of several dynamic components which, because of their interrelated characters, act as an entity with an objective or purpose. Once the components and their interrelationships are analyzed and understood, an underlying mathematical theory is built. With approval of the relevant scientific community, the

formulated theory may be used to represent the defined system and other systems of analogous properties.

To model a system is to represent it conceptually and mathematically. A conceptual model is simply a verbal and pictorial description of a system as defined by its boundaries, components, the relationships among its components, and the interaction of the system with the surrounding environment. The delimitation of a system is dictated by the purpose of the model. A mathematical model consists of quantitiaive expressions of relationships relevant to the system as suggested or established by systems analysts. As indicated by Halter and Miller (1976), the mathematical model is always less complete in detail and complexity than the real world. Nonetheless, valid mathematical models should reflect the real world and avoid over abstraction at the same time.

System simulation is an iterative method of investigating the dynamics of a system in an attempt to mimic its behavior with a mathematical model (Forrester, 1961; Hall, 1962; Halter and Miller, 1966; Naylor, 1966; Holland, 1967; Manetsch, 1967; McMillan and Gonzales, 1968). Simulation also includes processes for making a model operational; such processes consist of developing a computer logic and flow diagrams, writing the computer code, and implementing the

code on a computer. The art of simulation is being extended to areas which previously were too complex and difficult to analyze by conventional techniques; the biological world is an example (Baker and Curry, 1976).

Beef Cattle Management Studies

The objective of a cow-calf operator is to maximize profit in view of all important aspects of beef cattle production discussed earlier in this chapter. He must judiciously combine his basic knowledge in reproduction, nutrition and genetics to improve efficiency of feed utilization for optimal fertility, milk production and growth.

Koger and Hargrove (1983) compared three methods of selection and culling using experimental herds in Florida. Method one consisted of replacing necessary culls with heifers chosen at random; in method two replacements were selected on the basis of their own weaning weights and method three consisted of culling open and poor producing cows to the level permitted by the number of satisfactory replacement heifers. Those authors' statistical analysis showed that weight of beef sold from methods two and three exceeded method one by 2.2 and 6.6 percent, respectively. Clarke et al. (1982), in a deterministic simulation of cow-calf production under conditions in Washington State, found

that net income increased substantially if non-pregnant cows were culled in the fall or if cows were culled for not having a live calf at the end of the calving season. They reported an average net income of $1,286 when culling only for old age. The corresponding figure for culling non-pregnant cows was $4,025. Breeding herd size in both cases was 200 cows.

In terms of feed utilization, Hixon et al. (1982) found that creep-fed heifers were heavier at weaning than those which did not receive creep feed while nursing their dam. Prichard (1983) showed that creep feeding calves is beneficial to both the dam and its calf. Under this management policy, cows gain weight during a breeding season and produce larger calves at weaning. However, creep-fed heifers tend to produce less milk as cows than those which were not creep-fed.

Lee et al. (1982) stated that the optimum age for first calving beef heifers is approximately 30 months. They were convinced that efficiency of production can be increased by breeding heifers to calve as two-year-olds if an intensive management system is used. The following relevant recommendations were made:

(1) Avoid breeding heifers weighing less than 270 kg;

(2) Restrict pregnant heifers during the last 75 days of pregnancy to moderate quality pasture in order to avoid heavy birth weight and pelvic fat; and

(3) Put first calving heifers on a high level of nutrition during their postpartum interval.

Kunkle (1984) studied winter supplementation for a Florida cow herd. He recommended feeding supplements when forages contain less than 7 percent crude protein. Animal age and breed, and forage quality were recognized as factors affecting level and efficiency of supplementation.

Beef Cattle Production Models

Beef cattle researchers have integrated the information outlined above into mathematical models for various purposes in beef production. Many mathematical models are available in the form of computer programs, but details about most of them are unknown. Computer packages must address the complexity of agricultural systems in relation to environmental, climatic and genetic parameters (Menz and Knipscheer, 1981). They must be flexible as to allow examination of system behavior by systematic variation of parameters of interest.

Boyd (1976) used Dynamo II, a version of Dynamo programming language, to simulate beef cattle management systems for the Southeast. Boyd's program consists of two models. Model one, the cow efficiency estimator, computes

deterministically the total digestible nutrients (TDN) required by a cow and her calf. Variables considered for the cow are growth corrected for periodical changes in feed availability and nutritional requirements, maintenance and milk yield adjusted for month of lactation. For calves, TDN requirements for growth and maintenance are estimated. Model two, the herd efficiency estimator, utilizes the outputs of model one to estimate TDN requirements of a herd according to pregnancy rate, calf survival rate, death losses, heifer replacement and culling policies, and pasture availability. The parameters involved are assigned statistical means as fixed values.

Clarke (1979) built a deterministic model of a cow-calf production system in the Fortran language. The computer program of the model includes the following activities. Retention of replacement heifers is a function of cow death loss and culling policies. Growth is adjusted for breed effect and estimated according to the following expression:

$W_t = A(1 - be^{-kt})$ where

W_t is weight in kg at time t;

A is asymptotic mature weight;

b is a parameter relating birth weight to mature weight; and

k is maturing rate.

Clarke's model can adjust milk yield for cow age and month of lactation. It allows computation of the digestible energy (DE) requirement for maintenance, and correction of weight gain for sex and milk production. The values of the parameters of interest are statistical means. Clarke et al. (1982) used the model to study the effects of various culling criteria on net income under five mating plans. Clarke et al. (1984) applied the same model to economic study of alternative culling and crossbreeding strategies in beef production.

The Kentucky models are among the well acknowledged beef cattle production models; they are BEEF-NCl14, BEEF-SI56 and BABY BEEF. BEEF is the acronym for BEEF ENERGY and ECONOMIC evaluation for FARMS (Loewer et al., 1980). BEEF-NCl14 uses regression equations of the National Research Council to predict growth based on the California net energy system. BEEF-SI56 uses physiological age and body components (water, protein, fat and minerals) to predict growth. BABY BEEF enhances BEEF-NCl14 by including skeletal size, temperature and relative humidity to determine feed intake and utilization (Loewer et al., 1983).

BEEF-NCl14, BEEF-SI56 and BABY BEEF have basic similarities because both of these models predict herd performance (growth, maintenance, lactation and conception)

based on availability of pasture dry matter (DM). They simulate daily dynamics of the herd partitioned into 12 different categories according to age, sex and reproductive status. They compute DM demand of the herd as a function of metabolic body weight ($W^{0.75}$), metabolizable energy (ME) and digestible protein (DP) required for current activities. A normal weight-age relationship is maintained if DM demand is met. If available DM is equal to or greater than the DM demand, DM demand is met and all the current activities are performed. If DM available is less than DM demand, the physiological activities are performed in the following priority: maintenance, lactation, and weight loss or gain.

The Kentucky models were used to simulate animal growth and reproduction and to assess alternative strategies for beef production with land, energy and economic constraints. While comparing BEEF-NC114 and BEEF SI56, Loewer et al. (1983) concluded that BEEF-SI56 is more sensitive to extreme conditions of nutrition. The latest version of the Kentucky models, called GRAZE, incorporates animal and forage production considerations into one computer program.

The Kentucky models are currently integrated into the Kentucky Beef-Forage model, which allows great flexibility in formulating a management strategy by including factors such as land, money, animals, fertilizer, fuel, labor market

conditions, etc. (Loewer and Smith, 1986). The Kentucky Beef-Forage model can thus be used when selecting a set of management stragegies most suitable for a particular production system.

The Texas A&M University (TAMU) model gained some popularity because it was applied, with some success, in several beef cattle production systems of Africa, Latin America and the United States. The TAMU model essentially answers the following questions: given a feed resource, how can it best be utilized by a herd of cattle and what type of cattle can best utilize that feed resource? The model predicts, in a deterministic manner, the monthly performance of the herd in terms of maintenance, pregnancy, milk production, lean tissue growth and fat deposition based on predicted feed availability. Postnatal growth is partitioned into prepubertal and postpubertal segments and simulated according to Brody's equations modified to become functions of energy, age, body weight, structural size, pregnancy status, lactation state, sex and breed. Fertility is defined in terms of beginning of estrus cycle, resumption of estrus and conception probabilities. For heifers, beginning of cycling is a function of condition and growth rate. For cows, postpartum resumption of estrus is a function of condition, weight change, lactation and

postpartum interval. Cycling probability of heifers and cows is adjusted for condition and weight change, postpartum interval and exposure to a sexually mature bull.

Death loss is simulated as a function of month of the year, condition, age and parturition. Probability of perinatal calf death is adjusted for month of the year and age of dam. Death loss of calves between the ages of four and 12 months is a function of age, growth rate and ultimately energy availability. Cow death loss is assumed to be caused by parturition problems and is adjusted for postpartum interval, age and condition.

TDN requirements of a herd are adjusted for herd size, age, sex, animal size, condition, pregnancy status, lactation status, feed quality and feed availability. Dry matter intake is determined within limits imposed by digestibility, protein content and availability of the feedstuff, and age, size and current activities of the animal. If dry matter intake is inadequate, i.e., current estimated TDN requirements are not met, then current activities are performed in the following priority according to TDN availability: maintenance, pregnancy, milk production and lean tissue growth. In general, corrections are made in response to increasing discrepancy between intake and requirements in the indicated order:

- decrease of milk production and lean tissue growth;
- mobilization of fat deposits to meet the extra energy required;
- mobilization of fat deposits and a second decrease of milk production and lean tissue growth.

As implied earlier, excessive decrease in lean tissue growth over a long period of time can lead to infertility and death. Any excess of intake over requirements is deposited as fat.

In summary, the four models discussed above are deterministic and use statistical means as values of parameters. In the first three models, levels of performance are predicted and related nutrient requirements are computed. Information about availability of DM is required input for the computer package of the TAMU model.

Forbes and Oltjen (1986) recognized that livestock models remain in the exclusive domain of a limited number of systems-oriented scientists. Indeed, lack of proper documentation prevents the understanding of the basic assumptions of mathematical models and the functional mechanisms of computer programs (Van Dyne and Abramsky, 1975; Chudleigh and Cezar, 1982). Assistance by programmers of the model is often required in the application of computer packages by third parties. Hence, some models are unattractive to extension service agents and farmers.

Duplication of existing models is another result of poor documentation. Instead of modifying current models to include lacking desired features, most analysts of livestock systems are compelled to develop their own model that they can fully understand. Flaws mentioned above are among the reasons for engaging in the present work.

CHAPTER III
MODELING A COW-CALF PRODUCTION SYSTEM

UF COW-CALF was designed to answer the following fundamental question: given the average optimal growth and reproductive performances of a specified breed of beef cattle under known conditions of livestock production, what set of management strategies would meet nutritional requirements and ensure favorable net returns. This objective can be considered as that of a commercial beef cattle producer who would like to conduct a feasibility study prior to committing and allocating his resources to necessary productive activities.

Many livestock production models were available that could be applied to the objective stated above with some modification. However, the decision to develop UF COW-CALF was prompted by considerations explained below. There was an attempt to use the Texas A&M model, but difference in objectives was the primary reason for the departure from this package to UF COW-CALF. The Texas A&M model is primarily intended for predicting the level of performance that may be achieved with existing pasture. The Texas A&M

model does not advise the producer on what course of action to take in the case of sub-optimal performance. Nevertheless, it remains practically useful for developing countries where agricultural planning boards are anxious to know what they can achieve while facing the widely acknowledged scarcity of their resources.

The recognized lack of proper documentation (Forbes and Oltjen, 1986) made application of the Texas A&M and Kentucky models to systems under specific conditions, particularly those of Florida, difficult. Incomplete understanding of these models was not conducive to their adoption. Therefore, to have a completely understood model that could be modified with ease for use in research on management of livestock production in Florida, it was necessary to create UF COW-CALF.

In Chapter III, the following topics are discussed in the indicated order:

- elements of modeling and symbols used in the conceptual model;
- conceptual model of a cow-calf production system; and
- mathematical model of a cow-calf production system.

Elements of Modeling

Application of systems analysis methodology to agriculture, particularly to livestock production, is relatively new; therefore it is understood only by a few scientists involved. Earlier systems analysts realized the need to make this holistic method of scientific inquiry understandable and acceptable to interested scientists. Such a concern led to the development of standard symbols used in diagrams depicting the composition of a system, thereby facilitating communication among interested researchers. Acquaintance with the symbols shown in Figure 3-1 and briefly explained below is sufficient to read and understand subsequent diagrams.

Forrester (1961) used the symbols shown in Figure 3-1a, 3-1b and 3-1c for depicting systems of industrial dynamics. The level or value of an entity, denoted by variable X, is depicted by a rectangle as shown in Figure 3-1a. Arrows indicate the direction of flows to and from the variable level. Symbols F_{in} and F_{out} identify the flow rates. An example of level is given in Figure 3-4 where a cow contributes to the level of milk supply (flow in) which in turn contributes (flow out) to the level of feed supply.

Flows occur in and out of a level. Two types of flow are recognized (Forrester, 1961): material flow (Figure 3-

1b) and information flow (Figure 3-1c). One can see in Figure 3-2 that information about herd nutritional requirements is made available to the management. One can also see the flows of energy and protein supplement contributing to the level of feed supply.

Delays are common in discrete-time systems. Lewis (1976) dedicated a book to network models in population biology where he emphasized the occurrence of delays by developing a system of representation. Figures 3-1d, 3-1e and 3-1f are parts of the system. Figure 3-1d depicts a time delay element. Parameter T is the amount of delay in specified units. For instance, in Figure 3-3, new-born male calves are loaded into the class of suckling male calves (NSMC) and emerge ISP transitional intervals later, with ISP denoting the length of suckling period in months. Delays can also be depicted as a sequence of compartments, each representing a time class one transition interval in duration, as in Figure 3-1e. Figure 3-5e is an example of compartmented delays. It is a detailed representation of Figure 3-5d where the sequence of compartments is implicit.

The adder, or symbol for the addition process shown in Figure 3-1f, was also utilized by Lewis (1976). As depicted in Figure 3-3, the population of newborn calves is the sum of calves born to cows three years of age and older.

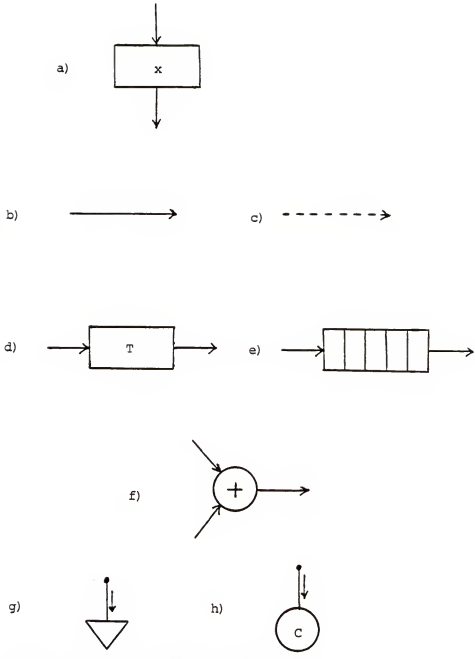


Figure 3-1. Some elements of modeling.

a) Symbol for level or state of an entity X. b) Pathway for material flow. c) Pathway for information flow. d) Delay with T transitional intervals. e) Delay depicted as a sequence of compartments. f) Symbol for addition process, also called adder. g) Population sink. h) Population store C.

Populations are also visualized as systems distributed by age class in a physical space. Smerage (1981) symbolized a population in physical space by a store as in Figure 3-1h. The arrow represents the flow of individuals into the store. Examples of stores of individuals of the same age class are seen in Figure 2-2. According to Figure 2-2, mature individuals of store C_2 keep reproducing until they are dead and transferred to the population sink. Figure 3-1g is the symbol of the population sink.

The Conceptual Model of the System

Definition of a system by identification of its boundary and major components is the first step in conceptual modeling. As stated earlier, the conceptual model of a system is simply its qualitative description by verbal and graphical means.

The system of interest in the present case is graphically defined in Figure 3-2, where a cow-calf production system consists of a pasture, the major source of feed, and a herd of brood cows, calves and heifers. Outputs of the system are cull cows and feeder calves for sale and information on nutritional requirements of the herd. The most important exogenous influence on the system is management. In response to herd nutritional requirements and information about cow and feeder calf prices, the

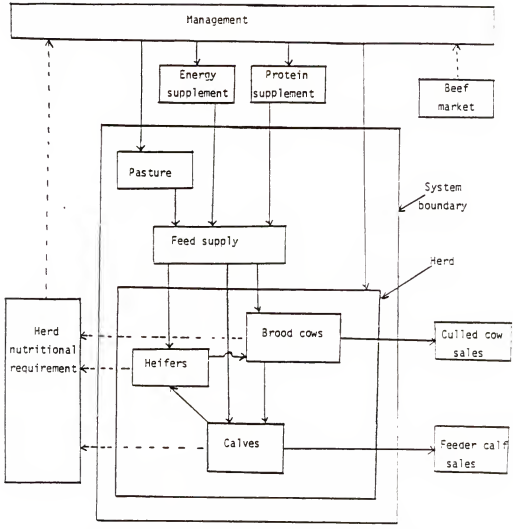


Figure 3-2. Component diagram of the cow-calf production system.

Cow-calf production system is conceptualized as consisting of a pasture as the major source of feed and a herd of brood cows, calves and heifers. Outputs of the system are cull cows, feeder calves for sale and information about nutritional requirements. The management insures that these requirements are met. Beef market, energy supplement and protein supplement are major exogenous elements related to the system.

management takes actions affecting, on one hand, feed supply through forage production and purchase of energy and/or protein supplement and herd composition, on the other hand. Management options are discussed in Chapter IV.

Once a system is defined and its components identified, one is interested in the relationships among the components. Relationships among the attributes of a single entity and the interrelationships between entities are conceptually described in a variable dependency diagram. Even though the cow-calf production system looks simple from the study of its component diagrams in Figure 3-2, it is indeed very complex. Such complexity can be appreciated only through analysis of all the attributes and relationships involved. Representation of all the relevant relationships in a single diagram would make it unreadable, so the variable dependency diagram is divided into two parts in this case. Part 1 is the populational diagram and part 2 concerns growth and development, lactation and nutritional requirements.

Populational Representation of a Cow-calf Production System

In general, population models do not include details about individual members. The focus is on properties of the population in aggregate. In the case of beef cattle, herd size and composition vary with time in response to birth,

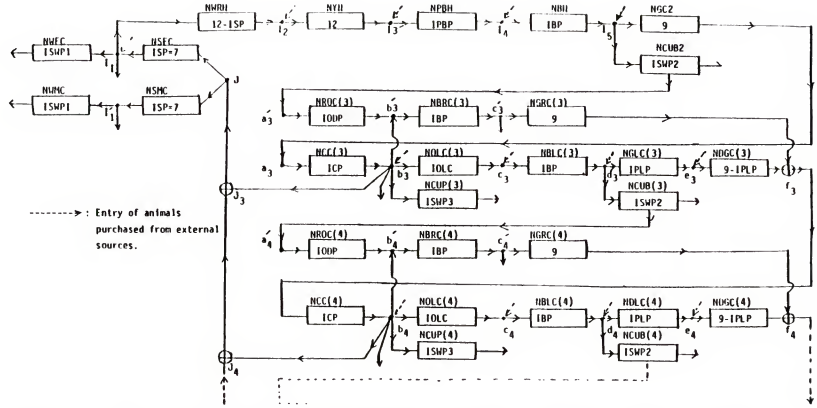


Figure 3-3. Populational representation of a beef cattle herd in a cow-calf production system.

Newborn calves from cows of ages ranging from 3 to n years are transferred into the pools of suckling male calves (NSMC) and suckling female calves (NSFC). Suckling calves have identical nominal age and are not identified by age of dam in this model. Replacement heifers are bred at two years of age. A cow open for the first time may be culled or retained. Cows are grouped by age class. Subclasses within an age class are based on physiological states of cows.

diagrammatic representation of a cow-calf herd which typically consists of brood cows of various ages at different stages of productive activity, replacement heifers and suckling calves. Suckling calves are present from birth to weaning. Generally bulls are added to the list, but when artificial insemination is applied, as assumed here, they are omitted. The summary below is presented to facilitate understanding of Figure 3-3 which depicts major classes of animals and their movements from one class to another.

Males. Suckling male calves (NSMC) are kept in the herd from birth to weaning. Animals which survive the suckling period (ISP) are weaned and become weaned male calves (NWMC), which can be sold immediately or kept in the herd while waiting for the appropriate sale date. All weaned male calves are sold eventually.

Females. Suckling female calves (NSFC) also remain in this category from birth to weaning. At weaning, a fraction of the survivors is selected to replace culled and dead cows. Retaining and buying additional replacement heifers (NWRH) and culling brood cows are means by which herd size is controlled.

Weaned replacement heifers are animals of ages ranging from weaning to 12 months. Yearling heifers (NYH) are animals 13 to 24 months old. It is assumed that females are

bred for the first time as two-year-olds. After they have reached 24 months of age, heifers waiting for the appropriate breeding season are referred to as prebreeding heifers (NPBH). During the breeding season heifers are called breeding heifers (NBH) and older cows are called breeding dry cows (NBDC) or breeding lactating cows (NBLC). NBDC refers to retained open cows (NROC) which are currently breeding. Brood cows may or may not be given a second chance after an unsuccessful breeding or calving. Retained open cows (NROC) are immediately culled if they fail either to become pregnant or to calve successfully after the second chance. After females have reached breeding age, they remain in the breeding-pregnancy-calving-lactating-breeding cycle until they are removed from the herd by death or culling. The following subclasses, based on various productive activities, are found within a given nominal age class: open retained cows (NORC), breeding retained cows (NRBC), gestating retained cows (NGRC), calving cows (NCC), open lactating cows (NOLC), breeding lactating cows (NBLC), gestating lactating cows (NGLC), gestating and dry cows (NGDC), cows with unsuccessful pregnancy (NCUP) and cows with unsuccessful breeding (NCUB). NCUP and NCUB refer to cows that are culled the first time they lose their calf and those that fail to conceive for the first time. These

animals may be sold immediately or kept while waiting for more favorable prices. Females in the culling age class fall into NCC, NCUP and NOLC subclasses only. Animals in this last class are removed from the herd immediately following an unsuccessful parturition or after they have weaned their calves.

Schematic Representation of Growth, Reproduction, and Lactation Processes and Nutritional Requirements

It is assumed that animals of the same sex in a beef cattle herd are physiologically and biochemically identical. Thus, one can describe biologically an entire herd by observing its average member. Variation among individuals due to breed effect and other factors may be accounted for by appropriate scaling of values of characteristic parameters.

Figure 3-4 represents metabolic processes of a cow in various physiological states. Feed is supplied through forage, the primary source, milk and supplementation. Ingested feed contains P_u (Protein uptake) and E_u (Energy uptake). Ingested P_u and E_u are transformed into digestible protein (P_d) and energy (E_d), respectively, by transformation D, representing digestion. Absorption of E_d and P_d into the blood stream as metabolizable energy (E_m) and metabolizable protein (P_m) is represented by transformation (A). Blood E_m and P_m are metabolized at

various metabolic sites. Metabolism (M) is a dynamic process that transforms matter and energy into various products according to sex and age of the animal. For a female animal, metabolic products of interest are body mass, products of conception and milk. Processes involved are growth, puberty, which marks sexual maturity, estrus, pregnancy and lactation.

Figure 3-4 views an animal as a biochemical network of storage, transport, transformation and sources. A biochemical approach to the study of growth, reproduction and other biochemical processes should be pursued in future research involving a team of biochemists, animal nutritionists, animal geneticists and animal physiologists. Such a team could continue the efforts of Oltjen (1986) and Forbes and Oltjen (1986) to develop cause-effect relationships describing a growth function. The mere description of body mass accumulation through time, fallaciously referred to as growth function, is not appealing to many growth physiologists. Nevertheless, such a growth function is used today due to the lack of a better technique. Animal growth, as a function of time, has been used to estimate animal nutritional requirements in real situations (Brown et al., 1976; Sanders, 1977; Brown, 1982). The nutritional requirements determined in this manner

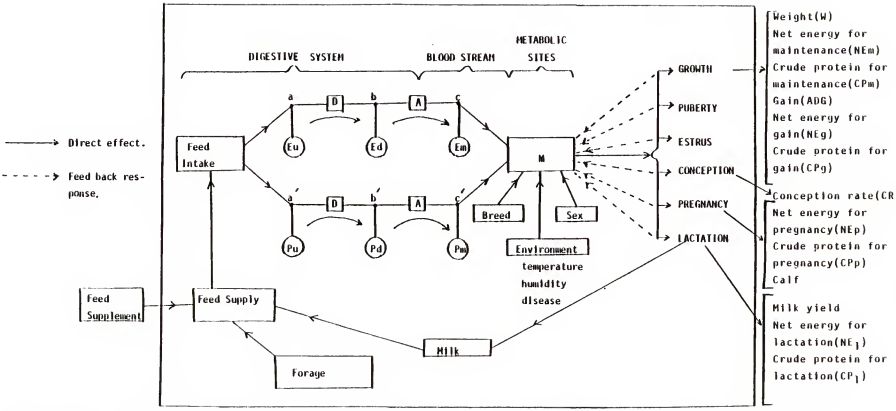


Figure 3-4. Conceptual representation of growth and development, reproduction, lactation and net energy and crude protein requirements.

Feed intake contains E_u (energy uptake) and P_u (protein uptake) transformed into E_d (digestible energy) and P_d (digestible protein), respectively, by process D (digestion). Transformation A (absorption) transfers E_d and P_d into the blood stream. Metabolism (M) is a time variable process which transforms E_m and P_m into a combination of products at a given time. Process M is under the influence of resulting products and breed, sex, and environment conditions.

provided useful and satisfactory feeding guidelines to beef cattle producers. This approach is adopted in the present study to analyze the end-products of metabolism (M) through successive stages of the life cycle.

The focus of this research concerns the average growth and reproductive performances of various breeds of interest under known geographic and climatic conditions. Net energy and crude protein required for productive activities are major outputs of the conceptual model. They constitute the primary information for assessing sources, quantity and quality of feed supply prior to committing other resources to any beef cattle production activity. Vitamins and minerals are not considered limiting factors in the model. However, it has been established that some essential minerals are limiting factors for cattle production in some areas, including Florida (Becker et al., 1965). The importance of minerals in livestock production should be given attention in future development of the present study.

To determine net energy and crude protein requirements for growth and reproduction in a cow-calf production system, various stages of the cattle life cycle are associated with appropriate attributes in the following manner.

Male and female suckling calves are characterized by net energy required for maintenance (NE_m), net energy

required for growth (NE_g), body weight (W), average daily gain (ADG), crude protein for maintenance (CP_m), crude protein for growth (CP_g), and death rate (DR). Similarly, attributes for weaned calves, weaned replacement heifers, yearling heifers and prebreeding heifers are W, ADG, NE_m, NE_g, CP_m, and CP_g. Growing and breeding open dry cows are described by W, ADG, NE_m, NE_g, CP_m, CP_g and pregnancy rate (PR). Growing and pregnant open dry cows are described by W, ADG, NE_m, net energy required for maintenance and pregnancy (NE_{m+p}), CP_m, CP_g, and crude protein required for pregnancy (CP_p). Mature pregnant and dry cows are on restricted feeding during the last two months of pregnancy in order to meet net energy and crude protein requirements for maintenance and pregnancy only and to avoid excessive fat accumulation that causes dystocia. The following attributes pertain to growing, lactating cows during the first two months of lactation: milk yield (MY), net energy required for maintenance and lactation (NE_{m+l}), crude protein for lactation (CP_l), W and CP_m. These animals will consume enough feed to maintain weight but not to grow during heavy lactation with excessive nutrient requirements. Mature lactating cows lose weight during heavy lactation. This weight loss corresponds to fat depletion in favor of milk production.

Table 3-1: LIST AND DEFINITIONS OF ACRONYMS USED IN THE CONCEPTUAL MODEL.

A:	represents absorption process in Figure 3-4
ADG:	average daily gain
CP_g:	crude protein required for gain
CP_l:	crude protein required for lactation
CP_m:	crude protein required for maintenance
CP_p:	crude protein required for pregnancy
CR:	calving rate
DR	death rate
E_d:	digestible energy
E_m:	metabolized energy
E_u:	energy uptake
IBP:	breeding period (fixes at three months)
ICP:	calving period (varies with breeding period)
IOLP:	maximum length of open lactating period; it corresponds to length of calving period
IPBP:	prebreeding period; it varies with calving period and applies to two-year-old heifers waiting for their first breeding season
IPLP:	length of pregnant lactating period
ISP:	length of suckling period, fixed at 7 months
ISWP1:	sale waiting period for feeder calves (it is variable and may be used to indicate length of backgrounding of feeder calves)
ISWP2:	sale waiting period for culled open cows

Table 3-1 -- continued

ISWP3:	sale awaiting period for cows without a calf at the end of calving season (variable)
M:	metabolism
MY:	milk yield
NE_g:	net energy required for gain
NE_m:	net energy required for maintenance
NE_{m+l}:	net energy required for maintenance and lactation
NE_{m+p}:	net energy required for maintenance and pregnancy
$NBDC_i$:	breeding dry cows; refers to breeding retained open cows and cows without a calf at i years of age; i = 3, 4, ..., culling age
NBH:	breeding heifers
$NBLC_i$:	breeding and lactating cows at i years of age
$NBRC_i$:	breeding retained cows at i years of age
NCC_i:	calving cows at i years of age
$NCUB_i$:	cows with unsuccessful breeding at i years of age
$NCUP_i$:	cows with unsuccessful pregnancy at i years of age
NGC2:	two-year-old gestating cows
$NGLC_i$:	gestating, lactating cows at i years of age
$NGDC_i$:	gestating and dry cows at i years of age
$NGRC_i$:	gestating, retained cows at i years of age
$NOLC_i$:	open, lactating cows at i years of age
NPBH:	prebreeding heifers; NPBH refers to two-year-old heifers waiting for their first breeding season

Table 3-1 -- continued.

$NROC_i$:	retained open cows at i years of age; NROC refers to cows open for the first time and those that lose their calf for the first time, which are retained in the herd and are waiting for next breeding season
NSFC:	suckling female calves
NSMC:	suckling male calves
NWFC:	weaned female feeder calves
NWMC:	weaned male feeder calves
NWRH:	weaned replacement heifers
NYH:	yearling heifers

The Mathematical Model

The development of a mathematical model is an essential step in systems analysis. It consists of expressing quantitative relationships existing among components of a system of interest. These relationships are implicitly contained in a conceptual model such as the one discussed above. The corresponding mathematical model was developed according to the methodology explained below.

One day was specified as the elementary unit of time. Herd dynamics were considered to be discrete phenomena while physiological processes, such as growth, were treated as being continuous in time. Discrete and continuous processes were analyzed over 30-day intervals and summarized monthly to reduce iterations in computing and thus, computing time. The mathematical model is presented in two parts for clarity. Part 1 concerns herd dynamics and part 2 describes growth, lactation and nutrient requirements for maintenance, growth, lactation and pregnancy.

The following details are necessary to facilitate the understanding of the mathematical model: the letter K denotes simulation time throughout Chapter III; three levels of representation are used for delays in a conceptual model of herd dynamic processes, as shown in Figure 3-5. Figure 3-5a depicts a total delay of three unit delays. Each of

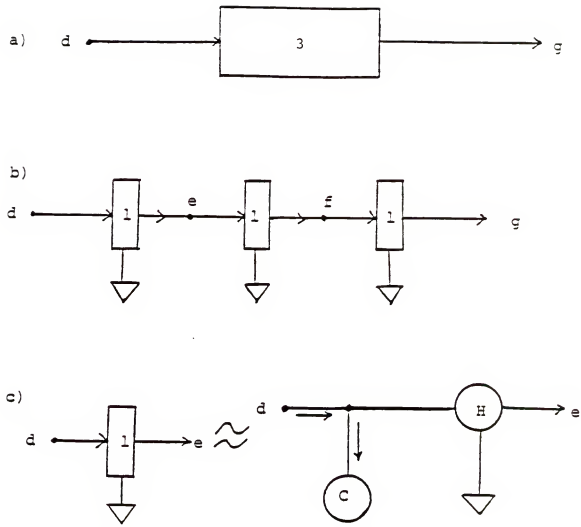


Figure 3-5. Explicit representation of a time delay during which herd dynamic process H occurs.

a) Total delay of three unit delays. b) Detailed representation of (a). c) Detailed representation of each unit delay: during each unit delay, individuals of store C are removed by death, or process H, and dumped into the population sink; survivors move to the next unit delay.

the three unit delays and their interfaces, which are implicit in Figure 3-5a, are represented in Figure 3-5b. Each unit delay corresponds to transformation H, which transfers surviving individuals from store C at discrete time to subsequent delay element, as shown in Figure 3-5c. Dead occupants of store C are dumped in the population sink.

Herd Dynamics

Figure 3-3 is a network of delays associated with age and functional classes within a beef cattle herd. Interfaces between delays are represented by nodes formed by interconnecting terminals of processes taking place in juxtaposed classes. Nodes identified by letter I refer to animals younger than the age at first calving. The subscript of interface I loosely reflects the age in months of individuals of juxtaposed classes. Interfaces labelled a, b, etc., are related to brood cows, and the alphabetical order reflects the order of activities that cows go through within a year. Numerical subscripts of these interface labels are ages of the animals. Interfaces with primed letters other than I (e.g., a') pertain to classes of open and retained cows. The boxes in Figure 3-3 represent delays associated with ages of animals of corresponding functional classes. For instance the box labelled NSFC with ISP=7 inside represents the class of suckling female calves with a

suckling period of seven months. This box is eqivalent to Figure 3-1e which shows the sequence of compartments representing time classes, each with one transitional interval in duration. Boxes and sequences of compartments are used to represent the dynamic processes of each selected class. Brief qualitative and mathematical descriptions of the processes of each class are presented.

Suckling male calves

The class of suckling male calves, shown as the box labelled NSMC with delay ISP=7 in Figure 3-3, is shown again in Figures 3-6a. Its internal unit delay elements are shown in Figure 3-6b. The class of suckling male calves is a pool of male calves born to cows of ages varying from three years to culling age. All the members of this class have the same nominal age by assumption to simplify programming. In reality calves are born at different months of the calving season and, therefore, should have different ages. It was also assumed that male calves and female calves are born in equal numbers. However birth of a male or female calf should be treated as a random event in the future. Length of the suckling period was fixed at seven months in the present study. The following expressions are mathematical descriptions of the dynamic processes of class of suckling male calves:

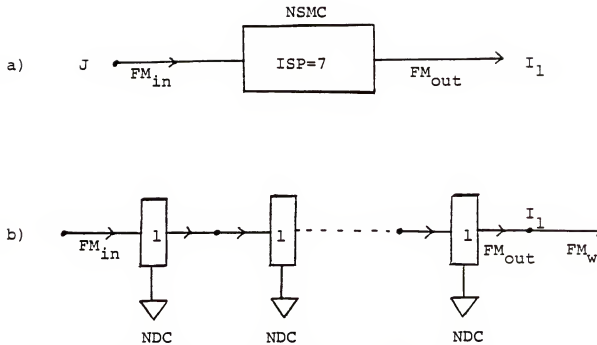


Figure 3-6. Delay of the suckling male calf (NSMC) class.

a) Time delay representing suckling period (ISP). b) Suckling period represented as a sequence of monthly transitinal intervals. Partition of suckling male calves as dead or surviving animals during each month of sukling period.

(3-010) $$FMC_{in} = 1/2 \sum_{J=3}^{KLGA} NCV_j$$

(3-011) $$NDMC(1)_k = FMC_{in_k} \times DRMC(1)_k$$

(3-012) $$NMC(1)_k = FMC_{in_k} \times [1-DRMC(1)_k]$$

(3-013) $$NDMC(2)_k = NMC(1)_{k-1} \times DRMC(2)_k$$

(3-014) $$NMC(2)_k = NMC(1)_{k-1} \times [1-DRMC(2)_k]$$

(3-015) $$NDMC(7)_k = NMC(6)_{k-1} \times DRMC(7)_k$$

(3-016) $$NMC(7)_k = NMC(7)_{k-1} \times [1-DRMC(7)_k]$$

(3-017) $$FMC_{out_k} = NMC(7)_k$$

(3-018) $$FMC_{w_k} = FMC_{out_k}$$

where FMC_{in_k} is the inflow of suckling male calves at time k corresponding to the beginning of calving season. The number of all calves born during a calving season to cows of age j at time k is symbolized by NCV_j. It was assumed that 50 percent of all calves born during a calving month are males and the other 50 percent females. The acronym for

culling age is KLGA. The number of male calves which survive in the i^{th} interval of ISP at time k is represented by $NMC(i)_k$. The number of dead male calves and death rate of suckling male calves in the i^{th} interval at time k are designated by $NDMC(i)_k$ and $DRMC(i)_k$, respectively. As time k advances, surviving individuals of one interval move to the next one as they grow older. Expression 3-013 means that the number of dead calves in the second interval of ISP in the present month is equal to the number of calves which have survived the first interval one month earlier, multiplied by death rate of the second interval in the present month. The outflow of male calves at time k that survived through ISP is represented by FMC_{out_k}. Flow of weaned male calves (FMC_{w_k}) is equal to FMC_{out}.

Weaned male calves

Another assumption of the present study was that all calves born during the same calving season are weaned at the same time and nominal age. Weaning age is fixed at seven months. Weaning date varies with calving season which in turn varies with breeding season.

Male calves that survive delay ISP exit as weaned male calves (NWMC) and enter sale waiting period for feeder calves (ISWP1). Sale waiting period is a parameter that can be used by the manager to indicate the duration of

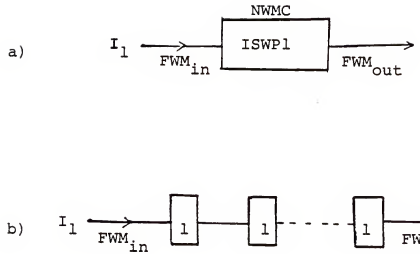


Figure 3-7. Delay of weaned male calf (NWMC) class.

a) Time delay representing a period during which sale steers are kept in the herd after weaning. b)Compartmental representation of the same time delay. ISWP1 is the variable for the number of unit delays.

backgrounding of feeder calves. It varies from zero to five months. Figure 3-7 depicts the class of weaned male calves; in Figure 3-7b, delay ISWP1 is a sequence of ISWP1 unit delays. Assuming that mortality is negligible in this stage, the following equations describe the dynamic processes of NWMC:

(3-019) $FWMC_{in} = FMC_{k-1}$

(3-020) $NWMC(1)_k = FWMC_{in}$

(3-021) $NWMC(2)_k = NWMC(1)_{k-1}$

(3-022) $NWMC(3)_k = NWMC(2)_{k-1}$

$\vdots$

(3-023) $NWMC(ISWP1)_k = NWMC(ISWP1-1)_{k-1}$

(3-024) $FWMC_{out} = NWMC(ISWP1)_k$

where $FWMC_{in}$ is inflow of weaned male calves at time k from the class of suckling male calves. $NWMC(i)_k$ is number of weaned male calves in i^{th} subinterval of ISWP1 at time k. $FWMC_{out}$ is the outflow of weaned male calves sold as feeder calves.

Suckling female calves

Figure 3-8a and 3-8b are illustrations of the box labelled NSFC in Figure 3-3. The dynamics of the class of suckling female calves are nearly the same as those of male calves. The only difference is that at the end of suckling period ISP, surviving female calves are weaned and divided into two groups. One group replaces culled and dead brood cows; the other group is for sale. Mathematical description of the dynamics of the suckling female calf class is as follows:

$$(3\text{-}025) \quad FFC_{in_k} = 1/2 \sum_{J=3}^{KLGA} NCV_j$$

$$(3\text{-}026) \quad NDFC(1)_k = FFC_{in_k} \times DRFC(1)_k$$

$$(3\text{-}027) \quad NFDC(1)_k = FFC_{in_k} \times [1\text{-}DRFC(1)_k]$$

$$(3\text{-}028) \quad NTDFC(1)_k = NDFC(1)_k$$

$$(3\text{-}029) \quad NDFC(2)_k = NFC(1)_{k-1} \times DRFC(2)_k$$

$$(3\text{-}030) \quad NFC(2)_k = NFC(1)_{k-1} \times [1\text{-}DRFC(2)_k]$$

$$(3\text{-}031) \quad NTDFC(2)_k = NTDFC(1)_{k-1} + NDFC(2)_k$$

$$\vdots$$

$$(3\text{-}032) \quad NDFC(7)_k = NFC(6)_{k-1} + DRFC(7)_k$$

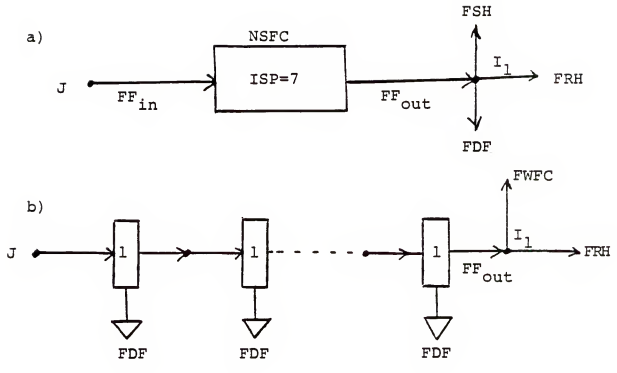


Figure 3-8. Delay of the suckling female calf (NSFC) class.

a) Network symbol of a time delay (ISP) corresponding to suckling period of female calves. b) Representation of ISP depicted with its sequence of compartments, one transitional interval of one month each. Partition of suckling female calves into dead and surviving animals during each month of suckling period. Partition of surviving individuals as replacement heifers and sale heifers at the end of suckling period.

(3-033) $NFC(7)_k = NFC(6)_{k-1} \times [1-DRFC(7)_k]$

(3-034) $NTDFC(7)_k = NTDFC(6)_{k-1} + NDFC(7)_k$

(3-035) $FRH_k = RR \times NFC(7)_k$

(3-036) $FDF_k = NTDFC_k$

(3-037) $FWFC_k = NFC(7)_k \times [1-RR]$

where FFC_{in_k} is inflow of suckling female calves at time k from cows of ages varying from three years to culling age. Acronyms KLGA and NCV_j are as explained earlier. Numbers of dead female calves and death rate for female calves are represented by $NDF(i)_k$ and NDFC(i), respectively, in i^{th} interval at time k. $NTDFC_k$ is total number of dead female calves at time k. FDF_k, FRH_k and $FWFC_k$ are flows of dead female calves, replacement heifers and heifers for sale, respectively, at weaning. Replacement rate (RR) can be determined automatically as a function of death rate and rate of culling of brood cows or it can be set by the management in order to control herd size in response to economic concerns and feed availability. Heifers selected for sale enter the sale waiting period for feeder calves (ISWPI) as weaned female calves (NWFC). The class of weaned

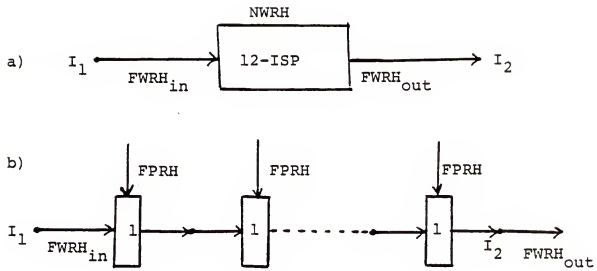


Figure 3-9. Delay of replacement heifer (NWRH) class.

a) Time delay between weaning and the age of one year for replacement heifers. b) Compartmental representation of the same time delay in monthly intervals. Delay in this case is equal to 12 months minus length of suckling period (12-ISP) since members remain in this class from weaning to 12 months of age.

female calves is similar to that of weaned male calves and does not need to be discussed explicitly.

Weaned replacement heifers

Weaned replacement heifers (NWRH) represent the fraction of female calves that survived the suckling period plus heifers purchased from external sources. These heifers are to replace dead and culled cows. Their ages range from weaning age to 12 months. It was assumed that individuals enter this period at the same nominal age. Replacement heifers are represented by the box labelled NWRH in Figure 3-3. Details of this box are given in Figure 3-9, and the following mathematical expressions describe dynamic processes of the replacement heifer class:

(3-038) $FWRH_{in_k} = FRH_k$

(3-039) $NWRH(1)_k = FWRH_{in_k} + NPRH(1)_k$

(3-040) $NWRH(2)_k = NWRH(1)_{k-1} + NPRH(2)_k$

(3-041) $NWRH(5)_k = NWRH(4)_{k-1} + NPRD(5)_k$

(3-042) $FWRH_{out_k} = NWRH(5)_k$

where FRH_k is as explained earlier. The symbol for inflow

of replacement heifers at time k is $FWRH_{in}$; $NWRH(i)_k$ and $NPRH(i)_k$ are number of replacement heifers and number of purchased replacement heifers respectively, at time k in the i^{th} transitional interval. The acronym for outflow of replacement heifers as yearling heifers is $FWRH_{out}$. All 12-month-old heifers enter the class of yearling heifers and remain there until they reach 24 months of age, at which time they are ready for breeding. For simplificaion of the computer programming, it was assumed that all heifers are bred for the first time at the age of two years. In further developments of the present study, breeding heifers at the ages of 12 months, 24 months, or other possible ages should be allowed by the computer program. The class of yearling heifers is represented by the box labelled NYH in Figure 3-3. Yearling heifers enter the prebreeding period (IPBP) as they reach 24 months of age. Prebreeding period is the interval between the age of 24 months and the beginning of breeding season. Heifers may turn 24 months old at the beginning of breeding season or earlier. Heifers bought from external sources may enter the yearling heifer or prebreeding heifer classes according to their age. Dynamic processes of these two classes and those of the weaned replacement heifer class have the same pattern. Death rate was assumed negligible in all three classes.

Breeding heifers

Replacement heifers entering their first breeding season are referred to as breeding heifers (NBH). The acronym for length of breeding season is IBP. In the present study, IBP is fixed at three months. Number of conceptions is checked monthly. At the end of each month of a breeding season, open heifers may be culled or retained as open cows (NROC). Mortality of breeding heifers was also assumed negligible. Heifers purchased from external sources may also join the breeding heifer class according to their age. Breeding heifers are represented by the box labelled NBH in Figure 3-3. Details of this box are shown in Figure 3-10. Dynamic processes of the breeding heifer class are expressed mathematically as follows:

(3-043) $FBH_{in_k} = FPBH_{out_k}$

(3-044) $FBH(1)_k = FBH_{in_k} + FHPB(1)_k$

(3-045) $FGC2(1)_k = PR2(1)_k \times FBH(1)_k$

(3-046) $FTGC2(1)_k = FGC2(1)_k$

(3-047) $FBH(2)_k = FBH(1)_{k-1} - FGC2(1)_{k-1} + FHPB(2)_k$

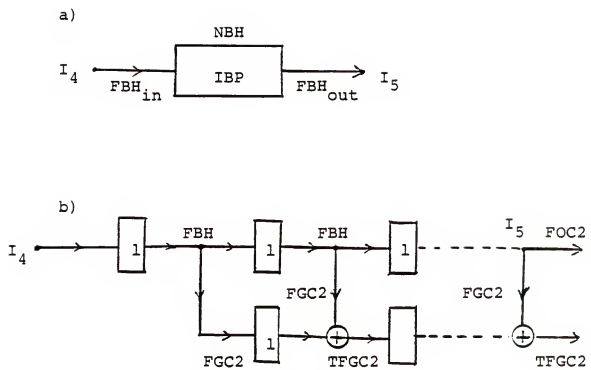


Figure 3-10. Delay of the breeding heifers class.

a) Time delay representing length of breeding season (IBP). b) Compartmental representation of the same time delay into monthly intervals. Partition of breeding cows into open and pregnant cows during each month of the breeding season.

(3-048) $FGC2(2)_k = FBH(2)_k \times PR2(2)_k$

(3-049) $FTGC2(2)_k = FTGGC2(1)_{k-1} + FGC2(2)_k$

(3-050) $FBH(IBP)_k = FBH(IBH-1)_{k-1} - FGC2(IBP-1)_{k-1} + FHPB(IBP)_k$

(3-051) $FGC2(IBP)_k = FBH(IBP)_k \times PR2(IBP)_k$

(3-052) $FTGC2(IBP)_k = FTGC2(IBP-1)_{k-1} = FGC2(IBP)_k$

(3-053) $FOC2_k = FBH(IBP)_k \times [1-PR2(IBP)_k]$

Acronym FBH_{in} is inflow of breeding heifers from the prebreeding period to the breeding period at time k. $FPBH_{out}$ is the outflow of prebreeding heifers at time k. $FBH(i)_k$, $FHPB(i)_k$, $FGC2(i)_k$, $PR2(i)_k$ and $FTGC2(i)_k$ are flow of breeding heifers, flow of heifers purchased for breeding, flow of gestating cows at two years of age, pregnancy rate of two-year-old females and flow of total two-year-old gestating cows, respectively, in the i^{th} transitional interval of breeding season at time k. The acronym IBP is as explained previously. The flow of two-year-old open cows at

time k is represented by $FOC2_k$. Two-year-old gestating cows enter the gestation period at conception. Length of gestation was assumed to be nine months of 30 days each. Two-year-old open cows may enter a sale waiting period or next breeding season waiting period according to the decision of the producer. The population dynamics in those periods are straight forward and do not require a detailed discussion.

Cows calving at three years of age (NCC3)

At the end of gestation, pregnant cows enter the calving period, which has the same duration as the breeding period. Number of calvings, cow mortality, neonatal mortality, number of open lactating cows, number of open cows without a calf and number of cows still pregnant are computed at the end of each month of calving season. Cows without a calf at the end of calving season may be retained or culled by decision of the manager. Following parturition, cows with a calf enter the open lactating period (IOLP) and then the open dry period (IODP) or pregnant and dry period (IPDP) when their calves are weaned. The box labelled NCC3 in Figure 3-3 represents class of calving cows at three years of age. Details of NCC3 box are given in Figure 3-11. The following sequence of equations describes the dynamic processes of the class of three-year-

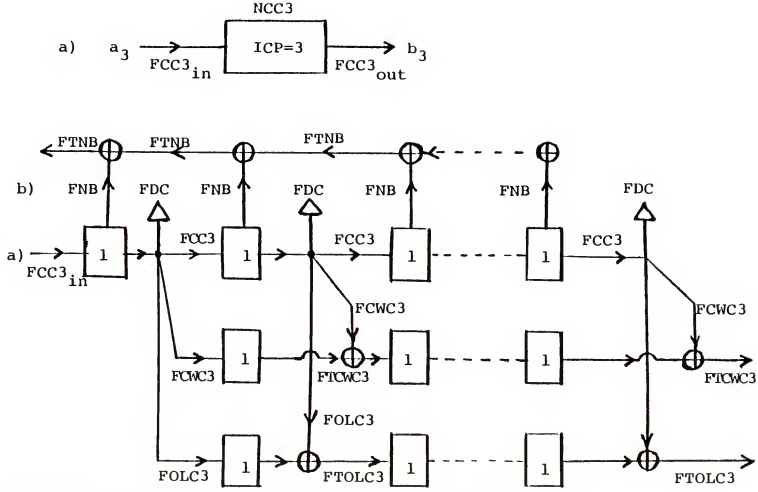


Figure 3-11. Dynamic processes of the class of three-year-old calving cows.

a) Time delay representing calving period (ICP). b) Compartmental representation of calving period in monthly intervals.

old calving cows:

(3-054) $FCC3_{in} = FTGC2_{k-1}$

(3-055) $FCC3(1)_k = FCC3_{in}$

(3-056) $NCVG3(1)_k = FCC3(1)_k \times CR3(1)_k$

(3-057) $FDC3(1)_k = NCVGS(1)_k \times DRC3(1)_k$

(3-058) $FPSC3(1)_k = NCVGS(1)_k - FDC3(1)_k$

(3-059) $FOLC3(1)_k = FPSC3(1)_k \times [1-DRNB(1)_k]$

(3-060) $FTOLC3(1)_k = FOLC3(1)_k$

(3-061) $FNB3(1)_k = FOLC3(1)_k$

(3-062) $FTNB3(1)_k = FNB3(1)_k$

(3-063) $FCWC3(1)_k = FPSC3(1)_k - FOLC3(1)_k$

(3-064) $FTCWC3(1)_k = FCWC3(1)_k$

(3-065) $FCC3(ICP)_k = FCC3(ICP-1)_{k-1} - NCVG3(ICP-1)_{k-1}$

(3-066) $NCVG3(ICP)_k = FCC3(ICP)_k \times CR3(ICP)_k$

(3-067) $FDC3(ICP)_k = NCVG3(ICP)_k \times DRC3(ICP)_k$

(3-068) $FPSC3(ICP)_k = NCVG3(ICP)_k - FDC3(ICP)_k$

(3-069) $FOLC3(ICP)_k = FPSC3(ICP)_k \times [1-DRNB(ICP)_k]$

(3-070) $FTOLC3(ICP)_k = FTOLC3(ICP-1)_k + FOLC3(ICP)_k$

(3-071) $FNB3(ICP)_k = FOLC3(ICP)_k$

(3-072) $FTNB3(ICP)_k = FTNB3(ICP-1)_k + FNB3(ICP)_k$

(3-073) $FCWC3(ICP)_k = FPSC3(ICP)_k - FOLC3(ICP)_k$

(3-074) $FTCWC3(ICP)_k = FTCWC3(ICP-1)_{k-1} + FCWCE(ICP)_k$

where $FCC3_{in}$ is inflow of three-year-old pregnant cows entering the calving season at time k as calving cows; $FCCE(i)_k$, $NCVG3(i)_k$, $FDC3(i)_k$, $FPSC3(i)_k$, $FOLC3(i)_k$, $FNB3(i)_k$, and $FCWC3(i)_k$ are the flow of three-year-old calving cows, the number of calvings from three-year-old cows, the flow of dead three-year-old cows, the flow of

three-year-old cows which survive parturition, the flow of three-year-old open lactating cows, the flow of new-born calves from three-year-old cows and the flow of three-year-old cows without a calf, respectively in the i^{th} subinterval of the calving period at time k; $CR3(i)_k$ and $DRC3(i)_k$ are calving rate and death rate, respectively, of three-year-old cows in i^{th} interval at time k; $DRNB(i)_k$ is death rate of newborn calves in the i^{th} interval of the calving season at time k; FTOLC3, FTNB3 and FTCWC3 stand for flow of total open lactating three-year-old cows, flow of total new-born calves from three-year-old cows and flow of total three-year-old cows without a calf, respectively. Length of calving period (ICP) is equal to the length of breeding period which was fixed at three months. The above equations are qualitatively explained below.

During a given month of a calving season, a given percentage of cows calve. A fraction of these cows survive parturition. Parturition survivors may lose their calves or may have live calves. Live calves, cows with a calf and cows without a calf accumulate throughout the calving period.

Dynamic processes of the population of older cows going through breeding, gestation and calving were analyzed in the

same manner as in the case of two- and three-year-old cows discussed above.

Growth, Lactation and Nutrient Requirements

Growth

Brody (1945) described animal growth as a phenomenon occurring in two phases. In the first phase, which starts at conception and ends at puberty, animals grow proportionally to the current weight. This hypothesis may be expressed mathematically as follows:

$$(3\text{-}1) \quad \frac{dW}{dt} = k_1 W_t$$

where dw/dt is growth rate, k_1 is a constant representing relative growth rate, and W_t is the current body weight. Expression (3-1) can be rewritten as follows:

$$(3\text{-}2) \quad \frac{dW}{W_t} = k_1 dt \qquad \text{which results in (3-3):}$$

$$(3\text{-}3) \int \frac{dW}{W_t} = k_1 \int dt.$$

One can deduce from (3-3) that the general solution to differential equation (3-1) is the following expression:

$$(3\text{-}4) \quad W_t = Be^{k_1 t}$$

where B is a constant of integration and t is time in days. Equation (3-4) is the growth function in phase one.

Brody (1945) observed that in phase two of animal growth, which lasts from puberty to maturity, growth is proportional to the total weight gain to be realized. If W_m is mature weight and W_t the current postpubertal weight, then postpubertal growth rate can be described in the following manner:

$$(3\text{-}5) \quad \frac{dW}{dt} = k_2(W_m - W_t)$$

Equation (3-5) can be rewritten and solved as follows:

$$(3\text{-}6) \quad \frac{dW}{W_m - W_t} = k_2 dt$$

$$\text{or } (3\text{-}7) \quad \int \frac{dW}{W_m - W_t} = k_2 \int dt$$

Equations (3-6) and (3-7) lead to the following general solution of differential equation (3-5):

$$(3\text{-}8) \quad W_t = W_m - Ae^{k2t}, \; t \geqslant A_p$$

where A is the unknown constant of integration, and A_p age (in days) at puberty and also the reference time for (3-8). Equations (3-4) and (3-8) are growth functions for phase one

and phase two, respectively. They provide a complete description of the animal growth.

Adaptation of Brody's animal growth model for the present study

Equation (3-4) describes growth from conception to puberty. The conception-birth interval is omitted in this study. At birth, i.e., at t=270 days if gestation lasts nine months of 30 days each, then

(3-9) $W_{270} = Be^{270k_1}$

If W_{270} represents birth weight, then:

(3-10) $W_{270} = W_b$ or $W_b = Be^{270k_1}$

If W_{270} is known, one can solve (3-10) for B which can be expressed in the following manner:

(3-11) $B = W_b e^{-270k_1}$

Substitution of B in (3-4) results in (3-12)

(3-12) $W_t = W_b e^{-270k_1}$

or (3-13) $W_t = W_b e^{k_1(t-270)}$

with $t \geqslant 270$ days, and the time reference corresponding to conception when t = 0. By rescaling time from days to

months and changing the reference time from conception to birth, prepubertal growth can be expressed as follows:

(3-14) $W_n = W_b e^{k_1(270 + 30n - 270)}$ or $W_n = W_b e^{30nk_1}$

where n is age of the animal in months. Equation (3-14) describes phase one of cattle growth in the context of the present study with $0 \leqslant 30n \leqslant A_p$ and A_p is age at puberty in days.

Generally, feeder calves are sold at weaning and their monetary value depends on their weight at that time. Let W_w and A_w be weight at weaning and age at weaning, respectively. Since k_1 must be known in order to simulate growth in phase one, it can be deduced by solving (3-4) based on W_s, A_w and W_b which are assumed known. Expression for k_1 is as follows:

(3-15) $k_1 = \frac{1}{A_w} \ln \frac{W_m}{W_b}$

Description of postpubertal growth in this study requires determination of k_2 and A as in (3-8). Let W_p denote weight at puberty, i.e., at $t = A_p$; one can write the following equation:

(3-16) $W_p = W_m - A$

Constant A can be deduced from (3-16) as follows:

(3-17) $A = W_m - W_p$,

reflecting Brody's principle that postpubertal growth is proportional to the weight gain to be realized.

Constant k_2 is still unknown. According to Brody, curves described by (3-13) and (3-8) meet at puberty, i.e., at the inflection point of the growth curve. The implication of this assertion is that growth must be continuous at A_p, i.e., the derivatives of (3-13) and (3-8) are equal at A_p. Since $k_1 W_b e^{k1t}$ and $k_2 A e^{-k_2(t-A_p)}$ are derivatives of (3-13) and (3-8), respectively, the following relationship is true at puberty, i.e., at t = Ap:

(3-18) $k_2 = k_1 W_b e^{k1A_p}$

Since $W_p = W_b e^{k1A_p}$ and $A = W_m - W_p$, one can express k_2 in the following simpler manner:

(3-19) $k_2 = \frac{k_1 W_p}{W_m - W_p}$

According to Brody, animals under an adequate nutritional regime reach puberty at one year of age, implying that puberty occurs at a constant age in cattle. In contrast, a study by Stewart (1977) to characterize puberty

and growth near puberty revealed that puberty tends to occur at a constant body weight within a breed. His data showed that, within the same genotype, individuals on high planes of nutrition reached puberty earlier than those on low planes of nutrition. Animals of both categories manifested signs of puberty at the same body weight but at different ages on the average. Table 3-2 shows standard pubertal weights of selected cattle breed types. Values in Table 3-2 were adapted from the work of Stewart. His conclusion seems plausible and was used as one basic assumption in cattle growth modeling. So W_p is considered given, but its corresponding time (A_p) must be determined. Since W_p and W_b are given, and k_1 can be determined according to (3-15), A_p can be deduced as follows:

$$(3\text{-}20) \quad A_p = \frac{1}{k1} \ln \frac{W_m}{W_b}$$

Because it was planned to simulate growth monthly, it was necessary to rescale time from days to months. Thus equation (3-8) must be rewritten as

$$(3\text{-}21) \quad W_n = W_m - Ae^{-k2(30n-Ap)}, \quad n \geqslant A_p/30$$

By setting θ equal to $(30n - A_p)$, the following expression is obtained:

TABLE 3-2. STANDARD WEIGHT AT PUBERTY IN KG OF SELECTED BEEF CATTLE BREED TYPES[a].

Sex	Breed type AA	BB	HH	AB	AH	BH
M	274.05	320.72	273.34	331.33	302.12	317.66
F	226.82	284.82	215.29	273.74	225.27	274.65

[a]Source: Stewart, 1977. AA: purebred Angus. BB: purebred Brahman. HH: purebred Herford. AB: Angus-Brahman cross. AH: Angus-Herford cross. BH: Brahman-Herford cross.

(3-22) $W_\theta = W_m - Ae^{-k2\theta}$

which is a simplified form of (3-21).

In conclusion, W_b, A_w, W_p, A_p and W_m are parameters that must be given in order to simulate growth.

Descriptions of cattle growth usually include weight gain. This consideration led to the following general expression of growth:

(3-23) $W_n = W_{n-1} + G_n$

where G_n is weight gain during the n^{th} month; G_n is calculated from theoretical growth curve and its continuous description in the two regions is as follows:

(3-24) $G_n = W_n - W_{n-1}$

where W_n is as in (3-14) for phase one, i.e., $0 \leqslant n \leqslant A_p/30$ and as in (3-21) for phase two, i.e., $n \geqslant A_p/30$.

Growth was assumed to be linear over any interval of one month, therefore the daily gain, a_n, was expressed as follows:

(3-25) $a_n = G_n/30.0$

In real life, many factors alter growth from the theoretical curve shown in Figure 3-12. In the case of beef cattle, heat and cold stress and periods of nutrient

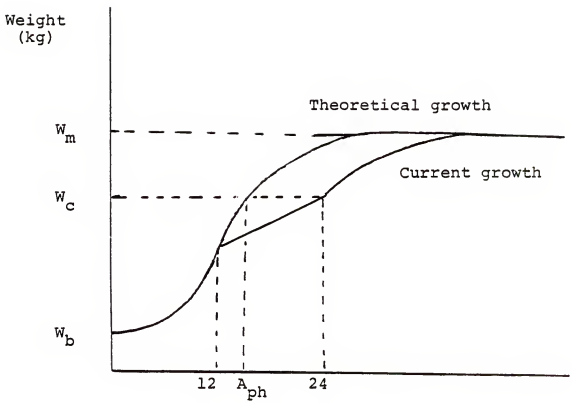


Figure 3-12. Theoretical growth and altered growth.

Refer to text for explanation of symbols.

deficiencies may cause growth to decelerate or to halt temporarily. For a variety of reasons, a producer may control growth by restricting feed intake over a time interval for a specific class of animals. For example, cow-calf producers in Florida allow heifers to grow at a target daily gain (TG_n) during the n^{th} month less than the theoretical gain between the ages of nine and 26 months in order to reduce the cost of feeding non-productive females. A producer needs to know nutrient requirements and the effects of artificially limiting gain on current and future growth patterns.

During a period of controlled growth limited to a target daily gain TG_n, body weight can be expressed in the following manner:

(3-26) $W_n = W_{n-1} + 30TG_n$

If TG_n is constant between the ages of 12 months and 24 months, growth is linear over that interval, as shown in Figure 3-12. Based on the works of Trowbridge et al.(1918) and many other researchers, growth is expected to resume at theoretical rate a_n, corresponding to current weight (W_c) at the end of restricted feeding. In order to describe growth in the ensuing interval, it is necessary to know the physiological age of the animal. Physiological age is defined as

age corresponding to a specified weight on the theoretical growth curve. Figure 3-12 shows that chronological age of 24 months corresponds to a physiological age A_{ph}. The current weight W_c expressed in the following manner:

$$(3\text{-}27)\quad W_c = W_m - (W_m - W_p)e^{-k_2[A_{ph}x\ 30-A_p]},\ A_p/30 < A_{ph} < 24$$

where A_{ph} is physiological age in months and the other variables are as explained earlier. Since W_c, W_m, W_p and A_p are known, one can solve (3-27) for A_{ph} which is expressed as follows:

$$(3\text{-}30)\quad A_{ph} = -\frac{1}{k_2}\ln\left[\frac{W_m - W_c}{W_m - W_p}\right] + \frac{A_{ph}}{30}$$

So after varying linearly, growth will resume at the relative rate k_2 from the physiological age A_{ph}.

Condition or fatness of a cow affects reproduction (Hargrove, 1984), lactation and energy requirements (Moe et al., 1972; Sanders, 1977). Sanders (1977) reported that under optimal conditions of feeding, as assumed in the present model, the ideal beef cattle body weight corresponding to theoretical growth consists of three percent fat at birth and 25 percent at maturity. Furthermore, the same authors indicated that the fraction of body fat between those extremes is linearly related to degree of maturity

defined as the proportion of current weight to mature weight. These observations were adopted as basic assumptions in assessing cow condition in this dissertation. Moreover, in periods of abundant, good quality forage or inactivity, weight gain of mature cows corresponds to excessive accumulation of fat. Body weight under these conditions was estimated as explained below.

Let E_{x_n} denote daily Mcal of net energy in excess of requirements for predicted performance at n months of age. It (E_{x_n}) is convertible to fat according to the following expression based on a report by Sanders (1977):

$$F_{d_n} = \frac{E_{x_n}}{9.1}$$

where F_{d_n} is daily kg of accumulated fat during the n months of age. Fat accumulation (F_{m_n}) during that month is simply:

$$F_{m_n} = F_{d_n} \times 30$$

and body weight of a mature cow is as follows:

$$W_n = W_{n-1} + F_{m_n}$$

It has been established that cows lose weight during months of high milk yield following parturition and that this loss corresponds to depletion of body fat deposits. Let TFAT be the total amount of fat accumulated by a mature

cow during a period of abundant feeding and/or low energy demand. Let LFL represent the length in months of the subsequent period of weight loss. Monthly weight loss is expressed as follows in the present model:

$$FL_n = \frac{TFAT}{LFL}$$

where FL_n is kg of fat depleted at the age of n months. Body weight during the period of fat depletion was estimated in the following manner:

$$W_n = W_{n-1} - FL_n$$

During pregnancy, cow body weight increased by the weight of the fetus. Since the fetus grows according to expression (3-4), one can write the following equation:

$$W_{fi} = Be^{k_1 30i}$$

where W_{fi} is monthly fetal body weight in kg and i is fetal age in months. Constants B and k_1 are as defined in expressions (3-11) and (3-15), respectively. Hence, a pregnant cow's body weight is expressed as follows:

$$W_n = W_m - Ae^{-k(30n-A_p)} + Be^{k130i}$$

where A and A_p are as defined in expressions (3-17) and (3-20), respectively.

So far, this discussion has focused on theoretical growth and current growth. Theoretical growth was described as occuring in two phases and consisting of three percent fat at birth and 25 percent at maturity. Percent fat between the two extremes is linearly related to degree of maturity. Current growth is a modification of theoretical growth as a consequence of restricted feeding, fat depletion and fat accumulation. Growth may also be partitioned into skeletal accretion and fat accumulation. The following assumptions were made to relate theoretical growth (W_θ), current growth (W_c) and skeletal growth (W_s) to one another, as illustrated in Figure 3-13:

- current growth is greater than or equal to skeletal growth and fluctuates about theoretical growth;
- theoretical growth is greater than skeletal growth.

Lactation

Sanders (1977) described milk production by beef cattle as follows:

(3-31) $PM = CFA \times CFM \times PMAe^{-0.08n}$

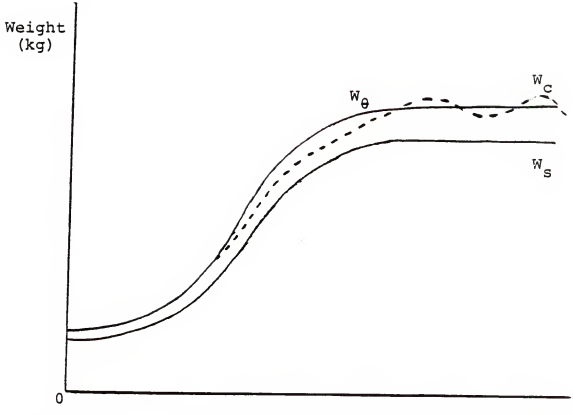


Figure 3-13. Comparison of theoretical growth (W_θ), current growth (W_c) and skeletal growth (W_s).

where PM is breed specific daily milk yield in kg during the n^{th} month of lactation; CFA and CFM are adjustment factors for age and month of lactation, respectively. PMA is the maximum attainable milk yield which varies with breed. Tables 3-2 and 3-3 show specific values of CFA and CFM. Body fat mobilization during heavy lactation contributes additional (9.1 x 0.84)/0.74 kg of milk per kg since one kg of fat contains 9.1 Mcal which are convertible to milk energy with 84 percent efficiency and energy concentration in milk is 0.74 Mcal per kg (Moe et al., 1972; Sanders, 1977). The Texas A&M model assumed that body fat energy can be transformed into milk energy with 100 percent efficiency.

Nutritional requirement

The primary objective of this research was to determine the amount of nutrients necessary to maintain a herd of a given size and structure at a specified level of performance. In development of the nutrition submodel, it was assumed that energy and protein are the major considerations and that minerals and vitamins are not limiting factors. Amount of nutrients (energy and crude protein) permitting optimal growth and lactation are determined by the model.

Energy requirements

Total digestible nutrient (TDN) and net energy (NE) are the two systems most frequently used in the United States to

TABLE 3-3. MILK YIELD CORRECTION FACTOR FOR MONTH OF LACTATION[1].

Month of Lactation	Milk Yield Correction Factor
1	1.00
2	0.97
3	0.92
4	0.84
5	0.78
6	0.73
7	0.69
8	0.65
9	0.60

[1]Source: Boyd, 1976.

TABLE 3-4. MILK YIELD CORRECTION FACTOR FOR AGE OF COW[1]

Age of cow (years)	Milk yield correction factor
2	0.70
3	0.80
4	0.88
5	0.94
6	0.98
7	1.00
8	1.00
9	0.98
10	0.94
11	0.88
12	0.80
13	0.79
14	0.58
15	0.44

[1]Source: Sanders, 1977.

express cattle energy requirements. The TDN system seems inadequate to represent the energy value of different feedstuffs, and should be replaced with a net energy system (Moe et al., 1972). Furthermore, because the goal of this study was to determine the total herd nutrient requirements accurately, use of the NE system seems most appropriate despite difficulties of measurement.

Lofgreen and Garrett (1968) introduced a net energy system which separates the requirements for maintenance (NE_m) from that for body weight gain (NE_g). Some researchers use total net energy of a feed for both maintenance and gain (NE_{m+g}) depending upon the level of feeding. Because of its lack of accuracy, such a system was rejected by Lofgreen and Garrett who recommended the separate expressions of NE_m and NE_g.

$\underline{NE_g}$. The net energy required for weight gain is simply the energy deposited in that gain. For males and females of any size, the energy stored in the weight gain can be expressed, respectively, as follows:

(3-32) $NE_g = (52.72G + 6.84G^2)\ W^{0.75}$

(3-33) $NE_g = (56.03G + 12.62G^2)\ W^{0.75}$

where NE_g is daily net energy for daily weight gain in Kcal,

G is daily weight gain in kg and W is body weight in kg. Since one day is the basic unit of time in this model, equations (3-33) and (3-33) are considered to express rates of energy storage in body tissues. If E_g represents total energy stored in total gain at time t, then:

$$(3\text{-}34) \quad \frac{dE_g}{dt} = NE_g$$

implying the following expressions:

$$(3\text{-}35) \quad E_{g_t} = \int_0^t (52.75G + 6.84G^2)\ W^{0.75} dt$$

in males and

$$(3\text{-}36) \quad E_{g_t} = \int_0^t (56.03G + 12.62G^2)\ W^{0.75} dt$$

in females. Since the method of integrating E_{g_t} is independent of sex, it is discussed with constants corresponding to females only.

Let us recall that $W_t = W_b e^{k_1 t}$ during the prepubertal growth and $W_t = W_m - Ae^{-k_2 t}$ in the postpubertal phase. Thus the integral equation (3-35) becomes:

$$(3\text{-}37) \quad E_{g_t} = \int_0^{270+A_p} (56.03G + 12.62G^2)(W_b e^{k_1 t})^{0.75} dt$$

in phase one, and

$$(3\text{-}38) \quad E_{g_t} = \int_0^t (52.75G + 6.84G^2)(W_m - Ae^{-k1t})^{0.75}dt$$

in phase two. Analytical solutions exist for phase one only, while the present model requires that E_g be integrated over both phases. The trapezoidal approximation method was adopted in order to circumvent this obstacle. As stated earlier, growth was assumed to be linear over a given month, with a_n being the growth rate in month n. Based on these assumptions, one can express the increment in net energy required for gain during the first month of life as follows:

$$(3\text{-}39) \quad DE_g = \int_0^{30} (56.03a_1 + 12.62a_1^2)\ W^{0.75}dt$$

Let Q_1 denote a constant expressed as follows:

$$Q_1 = 56.03a_1 + 12.62a_1^2$$

Expression (3-39) then becomes:

$$(3\text{-}40) \quad DE_g = Q_1 \int_0^{30} W_t^{0.75}dt$$

Let P_t equal $W_t^{0.75}$; P_t is also linear over an interval of one month and expression (3-40) can be rewritten as follows:

$$DE_{g_1} = Q_1 \int_0^{30} P_t dt$$

According to Figure 3-14, the area of trapezoid $O\ P_b P_1\ 1$ is as follows:

(3-41) $A = \frac{\overline{OP}_b + \overline{1P}_1}{2}$ i.e., $A_1 = \frac{P_b+P_1}{2} \times 30$

Based on the linearity assumption, one can write the following:

(3-42) $$\int_0^{30} P_1 dt = A_1$$

Since weight is also linear over the second month, the following expression is true:

(3-43) $$\int_{30}^{60} P_1 dt = A_2; \quad A_2 = (\frac{P_1 + P_2}{2}) \times 30$$

Expressions (3-42) and (3-43) imply, respectively, that:

(3-44) $DE_1 = Q_1 P_1$; $DE_g = Q_1 \times \left(\frac{W_b^{0.75} + W_2^{0.75}}{2}\right) \times 30$

and

(3-45) $DE_{g_2} = Q_2 P_2$; $DE_g = Q_2 \times \left(\frac{W_1^{0.75} + W_2^{0.75}}{2}\right) \times 30$

with $Q_2 = 56.03a_2 + 12.62a_2^2$. Based on equations (3-44) and (3-45), the monthly increment in energy requirement for gain can be expressed in a general manner as follows:

(3-46) $DE_g = 15Q_n(W_{n-1}^{0.75} + W_n^{0.75})$

and the average daily net energy required for gain at the age of n months is:

(3-47) $dE_n = DEg_n/30.0$

$\underline{NE}_m$. The partial net energy for maintenance is that quantity of energy needed to maintain energy equilibrium. It is estimated according to the following formula developed by Lofgreen and Garrett for growing and mature male cattle, growing non-pregnant females and non-pregnant, non-lactating mature cows. It is expressed as follows:

(3-48) $NE_m = 77W^{0.75}$

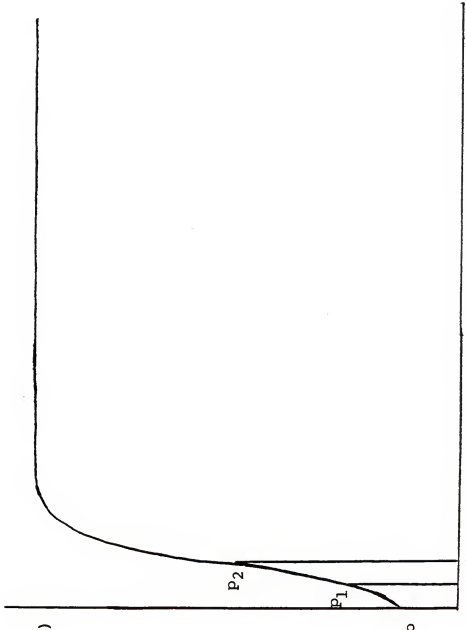


Figure 3-14. Illustration of trapezoidal integration method.

where NE_m is daily net energy for maintenance in Kcal. It was suggested in NRC (1978) that maintenance allowances be increased by 10 percent for good pasture and up to 20 percent for sparse pasture. An average increase of 15 percent seems acceptable for pasture conditions in Florida. In that case (3-48) becomes:

(3-49) $NE_m = 88.55\ W^{0.75}$

where NE_m is daily rate of energy requirement for maintenance. If E_m represents total energy required for maintenance at time t, then one can write the following expression:

(3-50) $$\frac{dE_m}{dt} = NE_m$$

Using the same trapezoidal method to integrate (3-50) over monthly intervals results in the following expression for the monthly increments in net energy requirement for maintenance at the age of n months:

(3-51) $DE_{m_n} = 1328.25(W_{n-1}^{0.75} + W_n^{0.75})$

The average daily net energy required for maintenance at the age of n months is equal to:

(3-52) $dE_m = DE_m/30.0$

Energy required for maintenance of cows depends on their activity. Pregnant cows require energy for maintenance and pregnancy (NE_{m+p}). According to NRC (1978):

(3-53) $NE_{m+p} = 104W^{0.75}$

which is of the same form as (3-47). Again, applying the trapezoidal method of integration results in the following expressions:

$$DE_{m+p} = 1560.0(W_{n-1}^{0.75} + W_n^{0.75})$$

and

$$dE_{(m+p)} = DE_{(m+p)} / 30.0$$

where $DE_{(m+p)}$ and $dE_{(m+p)}$ are monthly and daily increments in net energy required for maintenance and pregnancy at the age of n months. Net energy for maintenance of a pregnant and lactating cow, is the sum of NE_{m+p} and net energy for lactation (NE_l). Moe et al. (1972) expressed net energy requirements for milk production as follows:

(3-54) $NE_l = 75M$

where NE_l is daily Kcal of net energy required for four percent fat corrected milk, and M daily milk yield in kg.

The daily net energy required for maintenance of a non-pregnant lactating cow in body energy equilibrium and under conditions of limited physical activity is as follows:

(3-55) $NE_{(m+l)} = 74\ W^{0.75} + 75M$

where NE_{m+l} is the daily net energy requirement for maintenance plus lactation. With 15 percent increase in energy requirement due to grazing activities, equation (3-55) becomes:

(3-56) $NE_{(m+l)} = 85.1W^{0.75} + 75M$

By setting dE_{m+l}/dt equal to NE_{m+l}, one can express net energy requirement for maintenance plus lactation in the following manner:

(3-57) $DE_{(m+l)} = 1276.50(W_{n-1}{}^{0.75} + W_n{}^{0.75}) + 2250M$

(3-58) $dE_{(m+l)} = DE_{(m+l)}/30.0$

where $DE_{(m+l)}$ and $dE_{(m+l)}$ are, respectively, monthly and daily net energy required for maintenance and lactation at the age of n months.

Crude protein requirements.

Protein is required to furnish an animal with amino acids for various synthetic processes of the body. Protein requirements of each class of cattle have been derived by a factorial method (Mitchell, 1929). Based on this method, total crude protein can be expressed as follows:

(3-59) $TCP = U + S + F + G + P + L$ where

U: grams of protein lost through urine;

S: grams of protein lost in skin secretion, scurf and hair;

F: grams of fecal metabolic protein;

G: protein deposited in or associated with the increase in body weight of growing cattle;

P: protein deposited in products of conception;

L: protein required for synthesis of milk protein.

Daily crude protein requirement for maintenance is expressed as follows:

(3-60) $CP_m = U + S + F$

meaning that body protein lost through excretory processes must be replaced.

The National Research Council (1978) adopted the following specific expressions for the components of required protein:

$$U = 2.75\ W^{0.75}$$

$$S = 0.2\ W^{0.6}$$

According to NRC (1976), fecal metabolic nitrogen can be expressed as follows:

$$F = 4DMI$$

where F is grams of metabolic nitrogen and DMI of kg of dry matter intake. If DMI = 0.02W as suggested by Long et al (1971), then:

$$F = 0.08W$$

Since fecal protein contains 16 percent nitrogen, fecal metabolic nitrogen can be converted into equivalent fecal protein as follows:

$$F = 0.5\ W$$

for ruminating animals. The National Research Council (1978) expressed F in the following manner for milk-fed calves:

$F = 0.0125\ DMI$ i.e.,

$F = 0.00025\ W$

With reference to equation (3-58) one can write the following:

(3-61) $CP_m = 2.75W^{0.75} + 0.2W^{0.6} + 0.5W$

for ruminating animals and

(3-62) $CP_m = 2.75W^{0.75} + 0.2W^{0.6} + 0.00025W$

for milk-fed calves. If $\frac{dP_m}{d_t} = CP_m$, then one can express total protein required over n^{th} month as follows:

(3-63) $DP_{m_n} = 41.25(W_{n-1}^{0.75} + W_n^{0.75}) + 3.0(W_{n-1}^{0.6} + W_n^{0.6}) + 7.5(W_{n-1} + W_n)$

for ruminating animals and

(3-64) $DP_{m_n} = 41.25(W_{n-1}^{0.75} + W_n^{0.75}) + 3.0(W_{n-1}^{0.6} + W_n^{0.6}) + 0.00375(W_{n-1} + W_n)$

for milk-fed animals, where DP_{m_n} is monthly increment of crude protein required for maintenance at the age of n months. Daily crude protein requirement for maintenance during the same month is expressed in the following manner:

(3-65) $dP_{m_n} = DP_{m_n} / 30.0$

It was suggested in NRC (1984) that daily crude protein required for growing and finishing cattle could be expressed as follows:

(3-66) $CP_g = 268G - 29.4NE_g$

where NE_g and G are as explained earlier.

According to Long (1972) daily crude protein required for lactation can be expressed as:

(3-67) $CP_l = 0.07\ M$

where CP_l is grams of daily crude protein required for lactation and M is kg of daily milk yield. The monthly protein requirement for lactation in the present model is:

(3-68) $CP_n = 0.07PM$

where PM is as in equation (3-31).

According to NRC (1978), additional protein is required during the last 60 days of pregnancy and is estimated in the following manner:

(3-69) $CP_p = 1.136\ W^{0.7}$

where CP_p is additional daily crude protein required during the last 60 days of pregnancy. If DP_{p_n} is total crude

protein required during month n, then $\frac{dP_p}{dt} = CP_p$ and

(3-70) $$DP_{p_n} = 17.04(W_{n-1}^{0.7} + W_n^{0.7})$$

In general the coefficients of the mathematical expressions discussed above reflect minimum net energy and crude protein requirements. They are, however, subject to changes dictated by the environmental conditions in which cattle production takes place.

Feed intake and cost of feeding

Information acquired about net energy and crude protein requirements should lead to the kind, amount and cost of feedstuff the producer must make available to his herd in order to achieve the specified performance. The following sources of nutrients were used: pasture (forage), energy and protein supplements, and milk. Type and quality of available forage must reflect geographical location of the herd. The basic assumption for estimating feed requirements was that priority is given to the use of forage for ruminating animals, and forage and milk for suckling calves. If nutritional demand of ruminating animals cannot be met with forage, then supplementation is considered. It was assumed that suckling calves consume only milk during the first two months of life. From the age of two months to

weaning, they consume milk first and then graze if they cannot appease their hunger with available milk.

Estimating the amount of feed requires knowledge about the nutrient composition of available feed resources. Even though the National Research Council (NRC) tables of feed composition are readily available to a producer, it is preferable to use locally generated tables that reflect local conditions of forage production. In addition, information on variation of feed quality through time is required.

In this dissertation, efforts are solely devoted to estimating amount of feed necessary to supply determined net energy and crude protein requirements in the manner qualitatively described below.

Voluntary dry matter intake refers to the amount of dry matter an animal will consume until satiety, while under ad libitum feeding. In the present model, voluntary dry matter intake is computed as a function of net energy content of the forage and weight of the animal. In contrast, required dry matter is that amount necessary to provide nutrients in quantities corresponding to specified level of performance. It is calculated as a function of forage net energy concentration and animal net energy requirements.

Comparison of voluntary dry matter intake and required dry matter results in two interesting cases.

Case 1. When voluntary dry matter intake is greater than or equal to dry matter required, the forage supplying that dry matter is high in energy. In this case, actual forage intake is equal to voluntary forage intake. Total amount of crude protein in consumed forage is calculated. If it is less than crude protein requirements, the extra amount needed and corresponding quantity of protein supplement are estimated. Feeding cost is evaluated afterwards.

Case 2. When voluntary forage intake is less than that required for specified performance, the available forage is low in energy. The amount of extra energy required must be provided through an appropriate amount of energy supplement. A study by Golding et al. (1976) suggested that feeding energy supplement depresses voluntary roughage intake and that the extent of that depression is positively related to the quality of roughage used. It is assumed in this model that if energy must be supplemented, implying that available forage is of a poor energetic value, then depression of voluntary forage intake is negligible. Thus, actual forage intake is equal to predicted voluntary forage intake. An animal's uptake of crude protein through forage and energy

supplement is calculated and compared to crude protein requirement. If crude protein demand cannot be satisfied by forage, then the extra amount required is supplied through corresponding amounts of protein supplement.

These two cases apply to weaned and older animals. Suckling calves are fed according to their age. For calves less than two months old, milk is the only source of nutrients. Older calves are fed in the following manner according to their nutrient requirement: they consume milk first, then forage if necessary. It was assumed that milk alone or milk and forage provide enough nutrients for suckling calves.

The mathematical formulae and algorithms for evaluating herd feed consumption and cost are illustrated in Figure A-1; the symbols used are listed in Table A-1. Understanding of how feed requirements and costs are computed is facilitated by considering two underlying concepts.

By convention, the net energy system for beef cattle assigns two net energy values to each feedstuff. Publications of Lofgreen and Garrett (1968) and the National Research Council (NRC, 1981a) made a distinction between net energy available for growth (EC_g) and net energy available for maintenance (EC_m) in a single feedstuff to reflect different efficiency of utilization. Symbols EC_g and EC_m

refer to the net energy concentration of a feedstuff. Generally, net energy available for maintenance and net energy available for gain are expressed in Mcal per kg of dry matter. For growing, non-pregnant and non-lactating animals, required dry matter (DM_r) is estimated as the sum of dry matter required for maintenance (DM_m) and dry matter required for gain (DM_g). If the daily net energy required by an animal for maintenance (NE_m) and gain (NE_g) and the EC_g and EC_m for a given feedstuff are known, then daily DM_m, DM_g, and DM_r can be computed as follows:

$$(3\text{-}71) \quad DM_m = \frac{NE_m}{EC_m}$$

$$(3\text{-}72) \quad DM_g = \frac{NE_g}{EC_g}$$

$$(3\text{-}73) \quad DM_r = DM_m + DM_g$$

For pregnant dry, open lactating and pregnant lactating cows, DM_r is estimated according to the following expression:

$$(3\text{-}74) \quad DM_r = \frac{TNE}{EC_m}$$

where TNE (total daily net energy requirement) can be any combination of net energy requirements for lactation,

pregnancy, and maintenance, depending on the physiological state of a cow.

The second concept concerns an animal's daily voluntary dry matter intake (DMI). NRC (1984) expresses DMI in kg for breeding females in the following manner:

(3-75) $DMI = (0.1462 \times EC_m - 0.0517 \times EC_m^2 - 0.0074) W^{0.75}$

Using the trapezoidal method of integration, one can express the monthly increment in average monthly and daily voluntary dry matter intake, respectively, as follows:

$$DMI_n = 15(0.1462EC_m + 0.0517EC_m - 0.0074)(W_{n-1}^{0.75} + W_n^{0.75})$$

$$DI_n = DMI_n/30.0$$

NRC (1984) recommended adjustment for frame size. For instance, an increase of 10 percent in average feed intake is adequate for large-frame steer calves and medium-frame yearling steers. For large-frame bulls, average feed intake should be increased by five percent. There is no adjustment for medium frame steer calves, large-frame heifers and medium-frame bulls. A 10 percent reduction in average intake is considered appropriate for medium-frame heifers.

Once the required amounts of energy and protein supplements are estimated according to the algorithm

(3-79) $AMCPS_{j_1} = DCPS_{j_1} \times 30.0$

Total monthly costs for energy and protein supplements for the j^{th} class in month n is computed according to expressions (3-80) and (3-81).

(3-80) $TMCES_{j_1} = AMCES_{j_1} \times N_{j_1}$

(3-81) $TMCPS_{j_1} = AMCPS_{j_1} \times N_{1}$

where N_{j_1} denotes the size of the 1^{th} class in month j.

Total yearly costs of energy and protein supplements required by the th class in the ith year of production is estimated as follows:

(3-82) $$TYCES_{l_i} = \sum_{J=1}^{Z} TMCES_{j_1}$$

(3-83) $$TYCPS_{i} = \sum_{J=1}^{Z} TMCPS_{j_1}$$

where Z is the total number of months during which the members of the 1^{th} class are present in the herd. The total expenses for energy and protein supplements required by the entire herd in the ith year of production is as follows:

illustrated in Figure A-1, their costs can be calculated as follows:

(3-76) $DCES_j = DMES_j \times PES_i$

(3-77) $DCPS_j = DMPS_j \times PPS_i$

where j represents the month of the period during which members of the 1^{th} class are present, $DCES_j$ is daily cost for energy supplement in the j^{th} month for the average member of the 1^{th} class, $DMES_j$ is daily dry matter of energy supplement required by the average member of the 1^{th} class in month j, PES_i is price ($/kg DM) of energy supplement in the i^{th} year of production, $DCPS_j$ is daily cost of energy supplement required by the average member of the 1^{th} class in month j, $DMPS_j$ daily dry matter of protein supplement required by the average member of the 1^{th} class in month j, and PPS_i is price ($/kg DM) of protein supplement in the i^{th} year of production. Monthly expenses on energy and protein supplements for the average member of the 1^{th} class in month j are expressed, respectively, as follows:

(3-78) $AMCES_j = DCES_j \times 30.0$

$$(3\text{-}84) \qquad THCFS_i = \sum_{l=i}^{X} (TYCES_{li} + TYCPS_{li})$$

where X designates the total number of classes identified in a herd.

Fertilizer cost represents essentially the cost of pasture production which can be easily calculated knowing the number of acres of pasture, the application of fertilizer per acre and the price of fertilizer. Thus, the components of feed expenses in the ith year of production are $THCFS_i$ and the total fertilizer cost.

CHAPTER IV

THE COMPUTER PROGRAM

The computer program is a translation of the mathematical model into a form that allows behavioral analysis of the system of interest under specified circumstances. This chapter is designed to explain the translation of specific mathematical expressions of Chapter III into computer codes and to discuss the organization of these codes into a functional structure. An overview of the computer package is presented, followed by its potentials and limitations.

Overview

The ultimate goal of this work was the capability to analyze a Florida cow-calf production system using simulation methodology. Computer implementation of such an objective comes as the third step after development of conceptual and mathematical models of the system. In order to mimic the behavior of a real cow-calf production system, the mathematical expressions derived in Chapter III were translated into a computer program called UF COW-CALF.

UF COW-CALF consists of a main program and number of functions and subroutines. The main program reads input data by calling subroutine INPUT. It also coordinates the activities of other subroutines as shown in Figure 4-1, including printout of results. The subroutines are subdivided into two interconnected categories. Category I deals with herd population dynamics and Category II concerns growth, lactation, nutrient requirements, feed consumption and feed cost.

Category I subroutines update the ages of animals, transfer animals from one class to another, account for class size, mortality, natality, cullings and sales at appropriate times. The subroutines of Category II monitor growth, lactation and nutrient requirements and predict feed costs. For example, subroutine CALFEED of Category II computes feed intake of an average suckling calf by sex from birth to weaning. Subroutine MCALVES of Category I calculates the number of suckling male calves (NSMC). The link between Categories I and II is established when MCALVES transfers the number of suckling male calves to CALFEED for the purpose of estimating total feed intake by the entire class of suckling male calves at a given time. Connection between corresponding subroutines of Categories I and II is

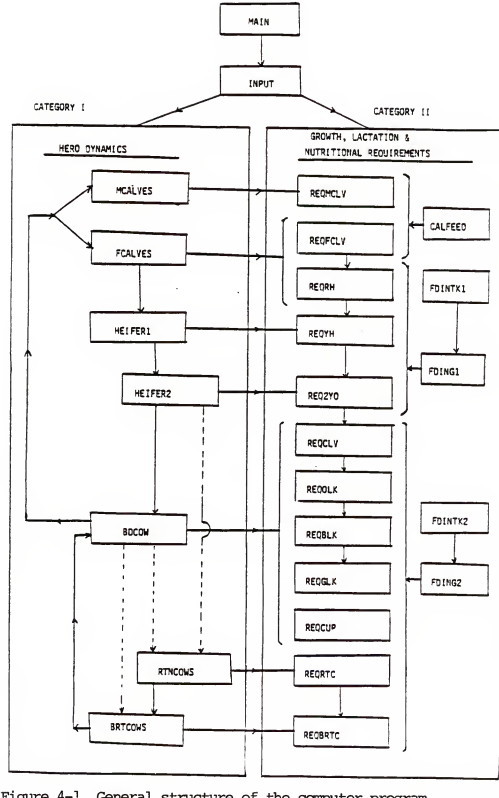


Figure 4-1. General structure of the computer program.

generally made in the above manner. These links are indicated in Figure 4-1.

Subroutines for Herd Dynamics

Subroutine MCALVES

MCALVES updates monthly the age of suckling male calves from birth to weaning and from weaning to the time they are sold as illustrated in Figures 3-5a and 3-5b. Mortality and number of suckling male calves are also calculated using expressions (3-010) through (3-018). Age and number of weaned male calves (NWMC) are computed while they wait to be sold. Subroutine MCALVES contains the set of computer statements implementing the series of equations that describe Figures 3-6a and 3-6b.

Subroutine FCALVES

FCALVES deals with suckling female calves (NSFC), weaned female calves (NWFC) and weaned replacement heifers (NWRH) in the same manner that MCALVES deals with suckling male calves (NSMC) and weaned male calves (NWMC). Both MCALVES and FCALVES are provided the number of newborn calves by subroutine BDCOW, as shown in Figures 3-6a and 3-8a, and expressed by relationships (3-010) and (3-025). Monthly partitioning of animals into surviving and dead individuals is performed according to equations of type (3-025) through (3-037). At the end of the suckling period, a

proportion of survivors is retained for replacement of dead and culled cows according to expression (3-035). The remaining survivors, estimated according to (3-037) are sold. FCALVES passes the number of weaned replacement heifers (NWRH) to subroutine HEIFER1 as they reach one year of age.

As its name suggests, HEIFER1 monitors the size of the class of yearling heifers (NYH) and updates the age of its members from 12 to 24 months. It is assumed that death rate is nil in this case. As yearling heifers reach 24 months of age, they are passed to subroutine HEIFER2. HEIFER2 gives a monthly account of their age and number until they become three years old. Since heifers are bred for the first time at the age of two years, HEIFER2 provides monthly information about those which become pregnant and the ones that remain open during a breeding season according to expressions (3-043) through (3-053). Heifers open at the end of a breeding season may be sold immediately or passed to subroutine RTNCOWS as retained open cows (NROC). Age and number of pregnant two-year-old females are updated by HEIFER2 during gestation. At the end of gestation, two-year-old pregnant cows (NGC2) are passed to subroutine BDCOW as three-year-old calving cows (NCC3).

Subroutine BDCOW

Subroutine BDCOW determines the numbers of calving cows (NCC), open lactating cows (NOLC), breeding lactating cows (NBLC), pregnant lactating cows (NGLC) and pregnant dry cows (NDGC) from the age of three years until culling. BDCOW also calculates monthly calvings (according to expressions (3-054) through (3-074), and successful breedings during corresponding seasons. At the end of a calving season, brood cows that lose their calves at parturition but are to be retained in the herd are transferred to the class of breeding dry cows (NBDC). This class is controlled by subroutine BRTCOWS. Number of stillborn calves and cows which die at calving is also computed within subroutine BDCOW according to equations (3-059) and (3-057), respectively. Newborn calves are transferred to the class of suckling male calves (NSMC) or suckling female calves (NSFC) according to their sex. It is assumed that male and female calves are born in equal proportions. During a breeding season, BDCOW provides the number of successful breedings on a monthly basis. At the end of a breeding season, lactating open cows are maintained in the herd until their calves are weaned and then they may be sold or retained and rebred during the subsequent breeding season.

In the latter case, they are referred to as retained open cows (NROC) and controlled by subroutine RTNCOWS.

Subroutine RTNCOWS

RTNCOWS stands for retained cow because the ages and numbers of open cows retained after unsuccessful breeding are updated within this subroutine. This operation extends from the end of a breeding season to the beginning of the subsequent calving season. These animals are then transferred to subroutine BRTCOWS as open dry cows (NODC).

Subroutine BRTCOWS

Subroutine BRTCOWS determines monthly the numbers and ages of open dry cows awaiting a breeding season, breeding dry cows (NBDC), and gestating retained cows (NGRC). During a breeding season, the number of successfully bred retained open cows is determined monthly. At the end of a breeding season, brood cows which remain open are systematically culled and sold. Gestating retained cows are transferred to subroutine BDCOW as calving cows (NCC) at the end of gestation period.

Reclassification of retained open cows as NROC, NODC, or NBDC is not based on any significant difference between these groups, nor is it practical for management purposes. It is the consequence of the structuring of available information to facilitate computer programming. Since

programming is an art, another programmer would probably organize given information differently.

Subroutines Dealing with Productive Activities of a Physiological Nature and Related Nutritional Requirements

Productive activities of a physiological nature refer specifically to growth or accumulation of body mass, maintenance of body mass, lactation and maintenance of pregnancy. Estimation of net energy and crude protein needs for the above functions is a major concern in this study. In this dissertation, "nutrient requirements" refers to requirements for crude protein and net energy, while "Nutritional Requirements" is intended for required net energy, crude protein, forage, protein supplement, energy supplement and feed cost. The following subroutines are groups of computer codes that permit simulation of growth, lactation and nutritional requirements of a beef cattle herd in a cow-calf production system.

Subroutine REQMCV

The acronym REQMCV stands for requirements of male calves. It updates the weight of an average male calf on a monthly basis and computes daily and monthly gain according to expressions (3-14), (3-24) and (3-25). Expressions (3-50), (3-46), (3-61), (3-62) and (3-65) are used to compute net energy and crude protein required to maintain current

weight and achieve weight gain. From this information and the number of suckling weaned male calves passed from subroutine MCALVES, REQMCV computes the total monthly net energy and crude protein required for the entire class. Feed intake and feed cost are calculated subsequently according to an algorithm contained in subroutines CALFEED and FDING1 based on equations (3-68) through (3-72).

Subroutine REQFCV

Subroutine REQFCV determines growth, nutrient requirements, feed intake and feed costs of suckling female calves only. It operates in the same manner as REQMCV, using the same equations with sex specific parameters. Estimation of nutritional requirements for the whole class of female calves is based on their number, as calculated and supplied by subroutine FCALVES.

Subroutine REQRH

Subroutine REQRH determines monthly body weight, weight gain, net energy and crude protein requirements for maintenance and gain of weaned replacement heifers from weaning to one year of age. It also calculates corresponding feed intake and cost. The same equations used in REQFCV are implemented here with adjustment for age by subroutine FDING1. Subroutine FCALVES determines the

number of replacement heifers and passes it to REQRH for estimation of nutritional requirements for the entire class.

Subroutine REQYH

Subroutine REQYH has the same structure as REQRH, using the same equations with different parameter values reflecting different ages. It refers to yearling heifers, i.e., females with ages ranging from 12 months to 24 months. Subroutine FDING1 is also used to implement relevant equations. Subroutine HEIFER1 determines and passes the number of yearling heifers to REQYH for the extrapolation of nutritional requirements of the average yearling heifer to that of the entire class nutritional requirements, according to Figure 4-1.

Subroutine REQ2YO

The mnemonic name for "requirements for two-year-olds" is REQ2YO. It is structured in the same manner as REQYH with the exception that net energy and crude protein requirements for two-year-old pregnant cows are included while calculating feed intake and feed cost. Equations (3-46), (3-47), (3-50), (3-51), (3-52), (3-61), (3-62), (3-65) and (3-69) are used. Expressions (3-52) and (3-69) reflect pregnancy. Subprogram FDING1 supplies the algorithm for computing feed intake and subroutine HEIFER2 provides size

of class of two-year-old cows for estimation of class nutritional requirements.

Subroutine REQCV

The role of subroutine REQCV is to estimate nutrient requirements of pregnant cows three years of age and older during the calving season. It estimates body weight and computes net energy and crude protein for maintenance and pregnancy using equations (3-22), (3-46), (3-51), (3-53), (3-64) and (3-65). Subroutine FDING2 contains the algorithms for implementation of equations (3-72) through (3-76) to determine feed requirements. Subroutine BDCOWS provides the number of calving cows for prediction of nutritional requirements for the entire class, as shown in Figure 4-1.

Subroutine REQOLK

Subprogram REQOLK estimates body weight, weight change and milk yield and then computes the corresponding net energy and crude protein required by open lactating cows three years of age and older. Equations related to body weight, adjustment of body weight for fat mobilization, milk production and nutritional requirements are implemented here. Feed intake and cost are determined through implementation of appropriate mathematical relationships in

subroutines FDING2 and BDCOWS, and specifically expressions (3-76) through (3-84).

Subroutine REQBLK

Nutrient requirements of breeding and lactating cows three years of age and older are calculated in subroutine REQBLK. Subroutines REQBLK and REQOLK are similar in structure and function. Both monitor the same productive activities occurring at two different periods. Subroutine BDCOWS also estimates the number of breeding cows and passes it to REQBLK. The latter calls FDING2 when estimating feed intake and feed cost for the same animals.

Subroutine REQGLK

Animals treated in this case are gestating and lactating cows, and gestating and dry cows, three years of age and older. REQGLK predicts body weight, weight change and milk yield, and then estimates net energy and crude protein along with feed intake and feed cost. Equations of particular interest are those related to net energy and crude protein requirements for maintenance, lactation and pregnancy. For specific details concerning those equations, one should refer to Chapter III. According to Figure 4-1, subroutines BDCOW and FDING2 are called to supply the population of the class of interest and the algorithm for estimating feed intake, respectively.

Subroutine REQCUP

The animals involved here are cows three years of age and older which, after losing their calves at parturition, are scheduled for culling by management and are waiting to be sold at an appropriate time. Subprogram REQCUP updates the body weight of those animals by predicting weight change and estimating the amount of net energy and crude protein necessary to insure gain for growing females. Feed consumption and feed cost are also computed using the algorithm in FDING2 based on equations (3-85) through (3-91).

Subroutines CALFEED, FDINTK1 and FDING1

Subroutine CALFEED contains the algorithms for computing milk and forage consumption by suckling calves from two months of age to weaning. The function of FDINTK1 is to compute the amount of feed supplement when pasture alone cannot provide net energy and crude protein in amounts required by weaned male calves, weaned female calves, replacement heifers and two-year-old heifers. Subroutine FDING1 is designed to estimate the amount of forage a member of a particular class can consume. It then calls FDINTK1 to compute the amount of feed supplement required. Finally, FDING1 calculates feed cost.

Subroutines FDINTK2 and FDING2

Subroutines FDINTK2 and FDING2 are similar to FDINTK1 and FDING1 with the exception that FDINTK2 and FDING2 calculate feed intake and feed cost for females older than 36 months. For details concerning the logical concepts involved in subroutines FDINTK1, FDING1, FDINTK2 and FDING2, one should refer to Figure A-1 and Table A-1 in the Appendix. Due to the similarities between these two sets of subroutines, only FDINTK1 and FDING1 are represented.

Management Options of UF COW-CALF

Is an ideal livestock computer package one that decides and simulates the next course of action based on the outcome of previous decisions by the manager? For instance, one that automatically adjusts herd size in response to expected local feed availability. Isolating one factor without consideration of its relationships with others may not result in a favorable return. A better alternative might be to develop a computer simulation package that recommends a solution based on a combination of production factors. However, a drawback to this approach is that it makes programming very difficult and the resulting package too complex. Furthermore, it may be too unrealistic to be useful to a producer.

It is believed that a computer package that quickly informs a manager about the outcome of his decision based on a set of management options is a practical tool for both the producer and the researcher. A number of management options are implemented by UF COW-CALF. It allows an individual to test various sets of management options and to identify the set most suitable to given production conditions. It provides means of exploring management practices generally related to factors controllable at the farm level and discussed below.

In its present state, UF COW-CALF can simulate the dynamics of established or new herds of known characteristics. These characteristics include initial herd size and composition, breed, reproductive rate, growth traits, milk production potential and mortality rate, all in relation to known production conditions.

The following culling and replacement policies are implemented by UF COW-CALF as means of controlling herd size and composition in response to a manager's assessment of forecasted beef price and predicted feed availability. If a user enters a value of one for IAUTR (Index for Automated Retention), UF COW-CALF automatically keeps weaned heifers to replace an equivalent number of dead and culled cows. An IAUTR value of zero is an indication to retain weaned

heifers according to the value of RR (Retention Rate) chosen by the user. Culling policies currently implemented by UF COW-CALF are those dealing with a cow's first failure to breed or calve, and two consecutive unsuccessful breeding seasons or parturitions. Setting the index for retention of open cows (IROC) to zero instructs UF COW-CALF not to retain cows open for the first time; an IROC value of one causes retention of cows of breeding age that fail to conceive for the first time but to cull them after two consecutive unsuccessful breeding seasons are culled. The index for retention of cows with parturition failure is IRCWNC (Index for Retention of Cows with No Calf).

An IRCWNC value of zero causes culling of cows which lose their calves. An IRCWNC value of one is an indication to cull cows for loss of two calves in two consecutive parturitions.

The third culling policy concerns the age at which it is considered unprofitable to keep a cow in a herd, as suggested by the works of Rogers (1972), Bently et al. (1976) and Melton (1980). The use of UF COW-CALF allows one to choose culling age (KLGA), in years, for his herd. Once a cow has reached KLGA, it is culled after its last calf is weaned.

Another feature of this program is choice of breeding season. This is in response to the concerns of a producer who has to breed his cows at a different time of the year dependent upon his particular geographical location. A researcher interested in the study of various breeding seasons on beef cattle productivity may also use UF COW-CALF if herd performance adjustment factors based on weather conditions are known. Usually it is recommended to choose breeding season so as to match months of high feed demand by the herd with periods of abundant good quality forage. According to UF COW-CALF, breeding season is set by selecting the first month of the year (IFRSTM) of simulated production and the length of breeding season. Since the production year starts with the calving season and since length of calving season is equal to that of the breeding season (IBP), breeding and calving seasons are fixed when the values of IFRSTM and IBP are set. The IFRSTM values of 1, 2, etc., to 12, correspond to January, February, etc., to December, respectively. In the present application of UF COW-CALF, IBP is set at three months.

Weaning age is variable and corresponds to the length of the suckling period (ISP). In the first simulation using UF COW-CALF, calves are weaned at the average age of seven

months, complying with the general practices of American cattlemen.

The terminal activity of a commercial beef cattle operation is the sale of feeder calves and culled cows. Various selling schedules are provided for by UF COW-CALF. Backgrounding of feeder calves is also allowed by the choice of the length of sale waiting period for feeder calves (ISWP1). An ISWP1 value of zero indicates that sale calves are to be brought to market immediately after weaning. The maximum value of ISWP1 is 12-ISP months meaning that feeder calves are not kept in the herd beyond one year of age. Some managers sell their culled cows as soon as possible to minimize feed cost. Others hope to maximize profit by selling them at a later date, corresponding to a more favorable price forecast. These goals are achieved by setting the length of sale waiting period for open cows (ISWP2) and that of cows without a calf at the end of calving season (ISWP3). Setting ISWP2 equal to zero causes lactating cows open at the end of breeding season to be sold immediately after their calves are weaned. Setting ISWP3 equal to zero causes cows without a calf to be sold at the end of the calving season.

The University of Florida's cow-calf model permits the choice of the duration of simulated production corresponding

to a planning horizon of a commercial cow-calf unit. Months of simulation (MS) or years of simulation (NSY) are the parameters used in this case. MS is used for a few months (less than twenty-four) of simulated production. If one decides to use MS, NSY must be set equal to zero and vice versa. The use of MS is recommended for testing the program when a new set of data is entered.

Only herds composed of animals of the same breed can be simulated. Consequently, many runs are necessary if one wishes to study more than one breed of cattle, using values of parameters that reflect breed effect each time. Such parameters are: weight at birth (WB), weaning weight (WW), weight at puberty (W_p), weight at maturity (W_m), milk production potential (PMA), pregnancy rate (PR), calving rate (CR) and death rate (DR). One should also enter values of PR that reflect cow age and females past ability to breed successfully. DR values must also reflect effect of cow age.

The data entry format permits easy use of the computer package by a non-programmer. Orderly entry of values of parameters related to growth, reproduction, lactation, feed quality and management options will produce an output containing well structured information that allows understanding of the outcome of previous decisions and

assist in planning future management strategies. Input information about feed quality and cost is printed first; it is followed by the daily nutritional requirements of the average member of each age and functional class. For each year, information about herd structure, mortality, cullings, sales and nutritional requirements is printed on a monthly basis in order to facilitate assessment of chronological trends of these production characteristics. A yearly summary is last in the output. It includes breeding herd composition by age, total revenue, total feed cost, other expenses, total expenses and total net revenue. Annual reports on revenues and expenses are useful to an agricultural economist concerned with the cash flow analysis of cow-calf operations. The effect of herd composition on net revenues can also be readily evaluated.

Limitations and Suggested Improvements of UF COW-CALF

The University of Florida's cow-calf model is intended to be a basic framework easily understood by interested scientists from different fields of study, namely, animal science, agricultural engineering and agricultural economics. These specialists should be able to create different versions of the package by simple modifications for research objectives in their own disciplines. Although

the present form of the program offers appreciable flexibility in management, it needs improvements.

The primary limitation of UF COW-CALF is the inability to adjust performance level of the herd to feed availability, especially in situations where feed supplementation is uneconomical. Therefore altering the model to estimate performance response to local nutritional conditions is highly recommended. Omission of factors permitting adjustment of production for climatic conditions, such as temperature and humidity, is one limitation of UF COW-CALF that needs correction. Such a feature would make the package applicable to various regions of the world. Partitioning of calves by sex is relevant to the fact that sex affects growth. However, it also is preferable to classify calves by their real ages and age of dam in order to allow analysis of the effect of cow age on calf weaning weight and, ultimately, net revenue. Such a feature will also make the study of the effect of varying culling age possible. To meet this objective adjustment factor of weaning weight for age of dam must be known and included in the package. It is also practical to adjust pregnancy and calving rates for age and breeding records of individual cows.

Currently, UF COW-CALF uses only mean conception and calving rates, but it is realistic to treat these two events and the birth of a male or female calf as occurring randomly. For quick analysis of breed effect on production and net returns, UF COW-CALF must be modified in the future to permit simulation of cow-calf production with herds containing more than one breed. Factors for adjustment of growth, lactation and reproduction for breeds must also be known. Necessary changes in the program include increasing the dimension of attributes of brood cows from two (month of the year and cow age) to three (month of the year, cow age and breed). However, in general required adjustment factors and probability distributions of random events are not well established. Therefore, significant improvement of UF COW-CALF can be accomplished only after experiments generating needed information are conducted.

The intention to keep UF COW-CALF simple led to the omission of the importance of minerals and vitamins. They should be included in future expansion of the present model. Additional computer statements are also required for deflation of various prices and income series for cash flow analyses. Making this program interactive and adaptable to personal computers and therefore accessible to more beef cattle producers is an ultimate goal of future developments.

Simultaneous incorporation of animal and forage production, and inclusion of bulls in the system are also major goals in future expansion of UF COW-CALF.

CHAPTER V

COMPARISON OF UF COW-CALF WITH OTHER BEEF CATTLE MODELS

The question "Why create UF COW-CALF while many beef cattle models are already available?" is legitimate and must be answered. Chapter V is intended for that purpose.

Weak attempts have been made in Chapters I, III and IV to differentiate UF COW-CALF from selected existing beef cattle models. Such a task can be systematically performed now that every aspect of the present model has been exposed. In order to facilitate understanding of the beef packages of interest and their contrast with UF COW-CALF, they are described with focus on their objectives, utilization of relevant concepts and their computer programs. Comparison along these three points is the object of the following subsection. The discussion is focused primarily on the Texas A&M and Kentucky models due to their popularity and acceptance as tools for management and study of beef cattle production. Other models are briefly reviewed.

The Kentucky Beef and Forage Models

There are several Kentucky beef and forage models, all differing in purpose and biological orientation. A relatively detailed discussion is devoted to BEEF since it is the beef forage simulation model from which other models are derived. The latter are summarized succinctly in an effort to contrast them with UF COW-CALF.

The fundamental question addressed in BEEF is formulated as follows: "Given the environmental conditions (temperature and humidity) affecting forage and animal production, the physiological state of an average animal and the quantity and quality (metabolizable energy and digestible protein contents) of locally produced forage, what productive performance can be expected?" The overall objective is to allow the manager to manipulate controllable factors in a way that will result in favorable economic returns (Loewer et al., 1980, 1981).

Some fundamentals of animal science are utilized as the first step in achieving the main objective. For instance, change in empty body weight is described as the consequence of accumulation or depletion of minerals, water and anabolism or catabolism of protein and fat. These processes are functions of diet and environment. Each of

the body components is expressed as follows (Loewer et al., 1983):

$$(5\text{-}1) \qquad y_i = A_i e^{\ln(\frac{a_i}{A_i})\ \frac{(t-T)^2}{T^2}}$$

where

y_i = potential change in weight (kg/day) of i^{th} component;

A_i = maximum potential rate of gain (kg/day) of i^{th} component;

a_i = 1) growth rate (kg/day) of ith component at conception if the animal has not yet reached the the inflection point of the sigmoid curve. 2) growth rate of ith component at a given age after the inflection point;

t = physiological age (days) or age of an animal developing at its maximum potential during its entire lifetime;

T = 1) physiological days from conception to the inflection point. 2) physiological days from inflection point to maturity.

The potential change in empty body weight equals the sum of all components:

$$(5\text{-}2) \qquad Y = \sum_{i=1}^{n} y_i$$

with n being the number of components (four in this case) and Y_i the potential change (kg/day) in empty body weight.

Energy requirements for gain are essentially for protein synthesis and fat accumulation, and are estimated as follows (Loewer et al., 1983):

$$(5\text{-}3) \qquad E_{day} = (E_F \times F) + E_p \times P)$$

where

E_{day} = energy required above maintenance to advance one physiological day;

E_F = energy stored in one unit of fat;

F = change in fat level per physiological day;

E_p = energy stored in one unit of protein; and

P = change in protein level per physiological day.

Dry matter intake (DMI) is estimated in relation to metabolizable energy (ME), digestible protein (DP) and moisture content of a feedstuff, skeletal size of the animal and the thermodynamic limits.

Some aspects of BEEF tend to indicate that it is intended for research more than management. For instance, the program user must specify parameters that are not readily available such as those related to dry matter

intake. Estimation of DMI according to BEEF requires the following:

- ME and DP levels below which DMI begins to be reduced;

- ME and DP levels below which DMI does not continue to be reduced;

- the percentage of optimum DMI associated with the lower ME and DP limits;

- the moisture content below which DMI is no longer reduced;

- the percentage of optimum DMI associated with the lower moisture content.

Reproduction is treated in terms of pregnancy rate based on cow weight, postpartum time and calf birth weight.

In view of the details discussed above, one should expect the BEEF computer package to be complex, and thus less accessible to non-programmers. Decoding the program for complete understanding prior to its application to specific research objectives in other geographic locations could be a difficult task, unless the user is a good programmer with background in animal science.

The other BEEF models are, in reality, versions or subprograms of the BEEF package. For example, BEEF-NC114, or BABYBEEF is a version of BEEF-S156. The major difference

is that BEEF-NC114 uses NRC regression equations to predict growth while BEEF-S156 uses physiological age and body components. Otherwise, the two models are essentially identical (Loewer et al., 1983).

The subprograms used to simulate forage production are commonly called GROWIT. GROWIT-1 and GROWIT-2 utilize maximum and minimum temperature, rainfall, soil fertility, harvesting and other cultural practices and grazing pressure to describe plant growth. The two versions differ in their description of forage quality. In GROWIT-1, ME and DP contents of a forage reflect its quality while GROWIT-2 incorporates plant cell wall and cell content to define potential digestibility of a forage.

Other subprograms of the Kentucky models are as follows:

- INTERFACE uses feed quality factors from GROWIT to predict dry matter intake;

- GRAZE incorporates animal grazing patterns with the plant growth concepts of GROWIT;

- SAM describes animal heat inflow and outflow;

- BEEFEM predicts body temperature based on body composition and surface area.

In conclusion the Kentucky models constitute a comprehensive package with research orientation, containing

minute details that result in a complex computer program. The very sophisticated nature of the package makes its application to other geographic areas very difficult as it must be completely understood in every aspect. Furthermore, it requires users to be skilled in programming and to have a good background in animal science.

The Texas A&M University (TAMU) Model

The Texas A&M model is a beef cattle simulation model whose objective is to predict the performance of a genetically uniform beef cattle herd in response to local feed availability. It is intended to be a management and research tool (Sanders and Cartwright, 1979a).

TAMU's description of animal growth is an adaptation of Brody's model. Structural weight corresponds to weight according to physiological age as in BEEF and to theoretical weight as in UF COW-CALF. It is described in phase one according to the following expression (Sanders, 1977):

$$(5\text{-}4) \quad R_t = \frac{W_p - W_b}{360}$$

and in phase two as follows:

$$(5\text{-}5) \quad R_t = 1.25\left(\frac{W_m - W_t}{W_m}\right)$$

where R_t is growth rate at time t, W_p structural weight at puberty, W_b structural weight at birth, W_m structural weight at maturity, and W_t weight at time t. Growth rate is adjusted for animal fatness and physiological state and quality and quantity of available feed, then it is integrated to obtain animal growth. Weitht at puberty is assumed to correspond to one year of age and expressed as a function of W_b and W_m. Expression (5-4) assumes that beef cattle growth is linear in phase one.

Other details of interest are related to reproduction. Fertility is defined in terms of the probabilities of estrus, resumption of estrus following parturition, and conception which are expressed as follows:

(5-6) $P_e = A \cdot F_m \cdot F_f \cdot F_l \cdot F_i \cdot F_d$

(5-7) $P_r = F_c \cdot F_d$

(5-8) $P_c = C \cdot F_c^{0.2} \cdot F_d^{0.2} \cdot F_c^{0.5}$

where P_e is probability of estrus, A maximum probability of estrus; F_m, F_f, F_l, F_i, and F_d are correction factors for degree of maturity, fatness, lactation status, postpartum interval and change in weight, respectively; P_r is

probability that estrus will resume following parturition and Pc probability that a cow exposed to a sexually mature bull will conceive. C is maximum probability of conception.

Death is also simulated as a random event in the Texas A&M model as illustrated by the following expressions:

(5-9) $D_n = M_n \cdot A_v$

(5-10) $D_c = 0.001M \times e^{140(1-\frac{W_t}{W_\theta})} \times A_c + [1-(\frac{12W_\theta}{12W_b+(W_p-W_b)A_c})^{0.64}]$

(5-11) $D_v = 0.0001M \times e^{140(1-\frac{W_t}{W_\theta})} \times A_v \leq 1.25$

where D_n is proportion of dead newborn calves, M_n month of the year effect on perinatal death, A_v effect of cow age on perinatal death, D_c proportion of dead suckling calves, M effect of month of the year on death of suckling calves, W_t, R_t, W , W_p and W_b are as defined earlier, A_c is effect of age (in months) of suckling calves on death, and D_v proportion of dead cows. Expressions $e^{140(1-\frac{W_t}{W_\theta})}$ and $[1-(\frac{12W_\theta}{12W_b + (W_p-W_b)A_c})^{0.64}]$ define effects of fatness and weight change, respectively.

This brief discussion of the Texas A&M model shows that it requires estimates of many parameters and therefore many data. Due to the level of detail encountered, the computer program is complex. There is a notable lack of a clear data entry format and instructions to facilitate the use of the computer package.

Contrasting the Kentucky, Texas A&M and Florida Models

Model Objectives. As explained earlier in this chapter, the Kentucky model is intended for research more than management. Its primary objective is to estimate reproduction and growth performance of a beef cattle herd based on environmental conditions affecting forage and animal production, the physiological state of an average animal and the quantity and quality of locally produced forage. Forage quality is defined in terms of metabolizable energy and digestible protein content.

The Kentucky and Texas A&M models have similar objectives to the extent that both predict herd performance based on available feed resources. Unlike the Kentucky model, the Texas A&M model expresses feed quality in terms of total digestible nutrients (TDN). Digestible protein and, especially, metabolizable energy are more difficult to measure, but more accurate than total digestible nutrients which is the least accurate but the easiest measurement of

the nutritive value of a feedstuff. The striking difference between the Texas A&M and the Kentucky models is that forage production is directly included in the objective of the latter.

The main objective of the Florida model is to predict the amount and kind of feed resources necessary for a satisfactory level of growth and reproduction of a genetically uniform herd of beef cattle to a specified environment. The estimation of the required amount of a feedstuff is based on its net energy and crude protein content and the net energy and crude protein requirements of an average animal in each age and functional class. Concern about accurate expressions of the nutritive value of feeds led to the choice of net energy and crude protein. The Kentucky and Texas A&M models use ME and TDN, respectively, as the bases for determining dry matter intake. In these cases, ME and TDN are later converted into net energy using factors published in NRC (1976, 1984).

UF COW-CALF is also intended for research and management as in the Kentucky and TAMU models. However its primary goal is to provide an easily understood framework that researchers in various fields of animal science and related disciplines such as agricultural economics and agricultural engineering can modify and adapt to their own

needs. In this perspective, bulls are excluded from the cow-calf sytem represented in UF COW-CALF while they are included in the Kentucky and TAMU models. The intention to keep UF COW-CALF simple also led to the omission of plant production which constitutes the uniqueness of the Kentucky model.

Utilization of basic concepts. The implementation of the objectives of the three models discussed so far requires the application of basic concepts in related fields of study. The most interesting case involves the concept of animal growth. While UF COW-CALF and the TAMU model adopt Brody's model in describing animal growth, one version of BEEF departs from this classical theory by expressing body weight as the sum of water, minerals, protein and fat accumulated through time in the manner described by equation (5-1). Such a departure may be an attempt to respond to the criticism that body weight should not be expressed as a mere accumulation of body mass through time but by a cause-effect relationship. However, expression (5-2) is not a cause-effect relationship. It also is a description of body weight as the accumulation of body mass partitioned into four components. The real difference with Brody's model is the form of the mathematical expression used.

UF COW-CALF and the TAMU model remain different in their application of the Brody model. While both UF COW-CALF and the TAMU models describe growth from conception to maturity, they differ in their basic assumptions. UF COW-CALF assumes that animals reach puberty at a breed specific constant weight, contrasting the assertion in the TAMU model that puberty occurs at the constant age of one year for all animals without consideration of breed and nutritional regime (Sanders, 1974).

BEEF and UF COW-CALF use the concept of net energy required for gain according to expressions (5-2) and (3-46), respectively. The second expression is an adoption of NRC regression equation. The TAMU model is consistant with the adoption of TDN by expressing energy requirement for gain as follows:

$$(5\text{-}12)\quad REQ_g = 0.8R_t + 5.56(0.22R_t)\frac{(2W_t + R_t - W_b)}{W_m - W_b}$$

where REQ_g is daily TDN requirement for gain and R_t, W_m, and W_t are as explained earlier.

The BEEF and TAMU models treat occurrence of estrus after parturition, conception and death as random events according to expressions (5-6) through (5-11). While the randomness of conception and death is recognized in UF COW-

CALF, average pregnancy and death rates are used that reflect the age and breed of an animal and its adaptation to a given environment. The use of average values of parameters is also consistent with the goal of keeping UF COW-CALF simple.

It is necessary to compare the computer programs which are versions of the mathematical models based on the concepts used to implement defined objectives.

The computer programs of BEEF, TAMU model and UF-COW-CALF.

It has been shown that the approach by the Kentucky model to express animal growth in terms of body mass partitioned into water, minerals, fat and protein accumulated through time is not different from the Brody model in principle. Even though it complicates the computer program by requiring a number of parameters, it is a method devised to estimate nutrient requirements, especially minerals. Brody's description of animal growth is less rigorous, but its direct adaptation in UF COW-CALF requires knowledge of a few parameters (birth weight, weaning weight, age at weaning, weight at puberty and mature weight) which can be readily obtained. This approach complies with the concern to keep UF COW-CALF simple.

The computer program of the Texas A&M model does not include clear data entry format instructions to assist its

user. In contrast, UF COW-CALF is a framework, therefore not a complete package, intended to implement basic management strategies and at the same time provide a simple and flexible research tool easily adaptable to various studies in beef cattle production.

Other Beef Cattle Models

Many other beef cattle models exist but are less known. The Colorado State University Beef Production model, the Simulation Model for Backgrounding Feeder Cattle in Florida, the Nebraska Computer Simulation of Plant and Animal Growth, and the Washington State Systems Analysis of Beef Production are among the biological simulation packages that have received less publicity.

The Colorado State University Beef Production model is a customized version of the Texas A&M University model (Bourdon and Brinks, 1986). Major changes include the addition of a subroutine simulating the effect of cold on gain and maintenance requirements during Colorado winters, supplementation of native range during winter, dystocia as a function of cow size and calf birth weight and an economic subprogram.

Computer Simulation of Plant and Animal Growth is an adaptation of the Kentucky BEEF models by researchers at the

University of Nebraska-Lincoln (Brown, 1982). Major changes were designed to adapt them to the conditions in Nebraska. Brown (1982) reported that even though animal and plant production could be simulated separately with appreciable accuracy, more modeling and programming studies were underway to predict plant and animal growth in a grazing situation.

The two cases above demonstrate that the Kentucky and the Texas A&M models can be adapted to other geographical locations despite their complexity. The new versions essentially answer the same fundamental question addressed in the originals. The possibility of modifying Texas A&M and the Kentucky models to meet completely different objectives, such as those of UF COW-CALF, is still questionable.

Spreen et al. (1985) developed the Simulation Model for Backgrounding Feeder Cattle in Florida. Their objective was to simulate the growth of feeder cattle on a forage based feeding program thus allowing economic evaluation of the projected costs and returns associated with a particular backgrounding program. The scope of their work is therefore limited in comparison with UF COW-CALF, BEEF and the TAMU model. Points of particular interest concern stocking rate, adjusting gain for breed, frame and heat stress, and the use

of feed additives. The real innovation is application of the concept of forage quality index in determining feed intake. Forage quality index (QI) is an estimate of the voluntary intake of TDN where the forage is fed alone and free choice, and is expressed as a multiple of the maintenance requirement as follows (Moore et al., 1984):

$$(5\text{-}13) \quad QI = \frac{\text{TDN intake}}{\text{TDN required for maintenance}}$$

A QI value of less than one is an indication that the animal cannot meet its TDN requirement for maintenance while consuming a particular forage. The use of TDN as a basis for determining dry matter intake marks another difference with UF COW CALF, which adopts the net energy system as a more accurate method of expressing the energy value of a feedstuff. As in the Kentucky and Texas models, TDN was converted into net energy using appropriate factors.

Clarke (1979) at Washington State University developed a deterministic beef production model whose major features are known through its application in evaluating beef cattle breeding systems, the effects of culling criteria on net income (Clarke et al. 1982), and alternative culling and crossbreeding criteria (Clarke et al. 1984). Growth is simulated according to Brody's model and the NRC (1976)

equations for estimating net energy requirements are adopted. Potential for milk yield (PMY) is fixed at 6kg/day for all mature straightbred and crossbred cows. Actual milk yield is found by adjusting PMY for age of cow and month of lactation. Average values are used for death, conception and calving rates. Estimation of parameters for productive traits of crossbred animals is based on predetermined heterosis and the average values for straightbred beef cattle. Culling criteria are governed by the ability to conceive and calve successfully, and unsoundness.

Inaccessibility to a thorough documentation of the Washington model makes a comprehensive comparison with UF COW-CALF impossible. However available information about the former points toward a high degree of similarity between the two systems.

CHAPTER VI

SIMULATION OF A HYPOTHETICAL COW-CALF OPERATION UNDER SELECTED MANAGEMENT STRATEGIES

The model developed in Chapter III has been implemented in UF COW-CALF, the computer program described in Chapter IV. The applicability of the model to real situations was tested in a hypothetical cow-calf operation reflecting environmental and economic conditions, and management practices in North Florida which constitute the object of this chapter. Breed specific average reproductive and growth performances under those conditions are also discussed.

Production Conditions

The University of Florida Beef Research Unit was used to climatically and environmentally represent North Florida. It is located at latitude 29 40' and at an elevation of 54.8 meters above sea level. The climate is considered subtropical with an average annual rainfall of 1,313 mm. Maximum and minimum average temperatures are 26.6 C and 7.0 C. (Koger et al., 1977). The major soil type is Leon fine soil (Restle et al., 1983).

Pensacola bahiagras (Paspalum notatum, Flugg) is the main forage of a hypothetical North Florida pasture from April to November. Rye (Secale cercale), ryegrass (Folium multiflorum) and clover (Trefolium repens) are available from December to March. An annual fertilizer application of 45.395 kg (100 lbs) per acre was considered as typical for most commercial cow-calf operations in North Florida. Parameters describing the quality of these forages are presented in Table 6-1. Forage dry matter content was assumed constant for simplicity. Molasses and soybean meal are available as energy and protein supplements, respectively. Their qualities are described in Table 6-2.

The choice of pensacola bahiagrass and clover reflects the general pasture management practice in North Florida. The expected qualities shown on Table 6-1 are also specific of the climactic and environmental conditions of North Florida. However, the production of rye and ryegrass is not so common in commercial operations due to high expenses involved and more importantly because of its dependency on rainfall at planting time, which is uncertain in North Central Florida. Hay or silage can be easily used as winter feed in future applications of UF COW-CALF if variation in their net energy and crude protein contents are known.

Management practices represent another dimension of environmental conditions under which cattle are raised. The calendar of management activities presented in Table 6-3 reflects current practices in Florida. Heifers are bred first at two years and calve as three-year-olds. In order to reduce feed expenses, heifers are not allowed to gain more than 0.22 kg (0.50 lbs) daily from weaning until their first breeding season.

The management must find the most profitable combination of culling policy and beef cattle breed under the physical conditions described above. He is faced with a choice between two culling practices. Culling policy A, or heavy culling, consists of culling all open cows, old cows and cows that lose their calves at parturition. Culling policy B, or light culling, consists of culling old cows, cows without a calf at the end of a calving season and cows open in two successive years. Cows are considered old and unproductive at the age of ten years. Two breeds of beef cattle are available for selection: Angus and Brangus. Their growth, lactation and reproductive characteristics are presented in Tables 6-4 and 6-5, respectively. Data shown in those tables are the expected performances of Angus and Brangus cattle under the conditions discussed above.

Procedure of Study

The manager chose to use UF COW-CALF to assist him in his search for the most profitable combination of culling policy and beef cattle breed. Fifteen years of production extending from 1970 to 1985 were considered for simulation. Nominal costs of major factors of beef cattle production and prices of calves and cows prevailing during the same period of time are presented in Tables 6-6, 6-7, 6-8 and 6-9. Fixed costs for land, cow herd and management charge are omitted.

Four scenarios resulting from combinations of two breeds and two culling policies were studied. Scenario one consisted of a commercial cow-calf production involving a herd of Angus cattle and the culling of all cows open for the first time. In scenario two, cows in a herd of Angus cattle were culled following two consecutive unsuccessful breeding seasons. The cow-calf production system in scenario three pertained to a herd of Brangus cattle with the elimination of all cows that failed to conceive for the first time. A herd of Brangus cattle was also considered in scenario four, but with elimination of all cows that remained open in two consecutive breeding seasons.

The hypothetical initial herd composition is presented in Table 6-10. It simply represents the state of the herd

at the beginning of the study which is the first month of the calving season. In this study, all culled and dead cows are automatically replaced with available weaned heifers. No reproductive improvement within breed was expected. Each simulation year starts with the calving season.

TABLE 6-1. QUALITY OF FORAGE USED IN THE SIMULATION

Parameters of forage quality	Month											
Pensacola Bahiagrass[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NE_m (Mcal/kg DM)[b]	0.0	0.0	0.0	1.72	1.39	1.34	1.25	1.15	1.10	1.10	1.10	0.0
NE_g (Mcal/kg DM)[b]	0.0	0.0	0.0	0.81	0.78	0.71	0.56	0.42	0.28	0.31	0.15	0.0
CP (% DM)[c]	0.0	0.0	0.0	8.9	8.9	8.0	7.0	6.0	6.0	7.0	6.0	0.0
DM (%)[c]	0.0	0.0	0.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	0.0
DM yield (kg/acre x 100)[d]	0.0	0.0	0.0	2.7	5.3	11.2	8.4	1.5	NA	NA	NA	0.0
Rye-Ryegrass-Clover[e]												
NE_m (Mcal/kg DM)[b]	1.42	1.39	1.39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.49
NE_g (Mcal/kg DM)[b]	0.85	0.78	0.78	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.92
CP (% DM)[f]	25.6	25.6	25.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.6
DM (%)[f]	20.6	20.6	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.6
DM yield (kg/acre x 100)	NA	NA	NA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	NA

[a]Reference number for grazed Bahiagrass is 2-00-464. [b]Source: Spreen et al. (1985). [c]Source: NRC (1978). [d]Source: Agronomy Research Report AY-10, Florida Agr. Exp. Stat. (1984). [e]Reference numbers for Rye, Ryegrass and Clover are the following: 2-04-70 and 2-01-380, respectively. [f]Average for % CP and % DM from Rye, Ryegrass and white clover. NA: not available.

TABLE 6-2. QUALITY OF PROTEIN AND ENERGY SUPPLEMENTS USED IN THE SIMULATION

Parameters of supplement quality	Month											
Molasses[a]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NE_m (Mcal/kg DM)[a]	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91	1.91
NE_g (Mcal/kg DM)[a]	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
CP(% DM)[a]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
DM(%)[a]	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
Soybean Meal[a]												
NE_m (Mcal/kg DM)[a]	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99
NE_g (Mcal/kg DM)[a]	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
CP(% DM)[a]	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
DM(%)[a]	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0	89.0

[a]Source: NRC (1976).

TABLE 6-3. CALENDER OF MAJOR MANAGEMENT ACTIVITIES

Activity	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Breeding season					X	X	X					
Calving season		X	X	X								
Weaning								X				
Calf sales								X				
Cow sales[a]				X				X				

[a]Cows sold in April are those which lost their calves at parturition. Cows sold in August are cows that have reached culling age and those that are culled for unsuccessful breeding season.

TABLE 6-4. PARAMETERS OF GROWTH

Breed	Birth weight[a] (kg)	Weaning weight[a] (kg)	Age at weaning[a] (days)	Weight at puberty[b] (kg)	Mature weight[c] (kg)
AA	25.03 (26.67)[d]	200.6 (213.10)[d]	233 (233)[d]	226.82 (274.05)[d]	425.10 (442.10)[d]
AB/BA	28.71 (30.48)[d]	214.37 (227.63)[d]	225 (225)[d]	273.74 (331.33)[d]	493.75 (513.50)[d]

[a]Source: Restle et al. (1983). [b]Source: Stewart (1977). [c]Estimates from data recorded at the Beef Cattle Research Unit of the University of Florida. [d]Numbers inside parentheses pertain to males.

TABLE 6-5. PARAMETERS OF HERD DYNAMICS AND MILK YIELD POTENTIAL[a]

Breed	Milk yield Potential (kg)[b]	Pregnancy rate (%)[b]	Perinatal death rate (%)[d]	Cow death rate (%)[b]	Calf death rate (%)[d]
AA	5.00	84.0(88.5)[c]	3.9	2.0	3.0
AB/BA	5.44	85.5(90.0)[c]	7.8	2.0	2.1

[a]Estimates from data generated at the Beef Cattle Research Unit of the University of Florida. [b]Source: Boyd (1976). [c]Numbers inside parentheses pertain to cows five years old and older, those outside parentheses to younger cows. [d]Source: Restle (1983).

TABLE 6-6 UNIT COST OF MAJOR PRODUCTION FACTORS

Production year	Labor[a] ($/hour)	Fertilizer[b] ($/kg)	Soybean meal[b] ($/kg DM)	Molasses[b] ($/kg DM)	Interest rate[a] (%)
1970	1.64	0.058	0.138	0.00	5.9
1971	1.73	0.061	0.140	0.00	5.8
1972	1.84	0.063	0.162	0.074	6.0
1973	2.00	0.077	0.346	0.105	6.1
1974	2.08	0.125	0.255	0.132	6.6
1975	2.26	0.160	0.219	0.124	6.9
1976	2.46	0.140	0.264	0.126	6.2
1977	2.65	0.135	0.319	0.139	7.3
1978	2.84	0.149	0.288	0.141	7.3
1979	3.27	0.158	0.321	0.173	7.7
1980	3.00	0.213	0.339	0.205	8.7
1981	3.87	0.149	0.366	0.231	8.6
1982	3.84	0.216	0.333	0.214	9.6
1983	3.81	0.218	0.353	0.214	9.9
1984	3.80	0.220	0.329	0.213	9.6
1985	3.80	0.222	0.256	0.204	8.0

[a]Source: Agricultural Statistics, USDA. [b]Source: Agricultural prices, USDA.

TABLE 6-7. AVERAGE PRICE ($/KG) OF LIVE WEIGHT (ALL GRADES OF STOCKER STEERS)[a]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970	0.60	0.61	0.66	0.65	0.62	0.63	0.62	0.63	0.59	0.59	0.57	0.56
1971	0.59	0.63	0.63	0.63	0.64	0.62	0.63	0.64	0.63	0.63	0.64	0.67
1972	0.71	0.73	0.72	0.70	0.74	0.76	0.80	0.79	0.76	0.78	0.76	0.76
1973	0.90	0.99	1.09	1.04	1.06	1.01	1.10	1.26	1.02	0.98	0.88	0.87
1974	1.00	0.93	0.88	0.88	0.73	0.64	0.62	0.57	0.49	0.46	0.42	0.44
1975	0.64	0.43	0.50	0.52	0.52	0.50	0.46	0.51	0.52	0.52	0.55	0.59
1976	0.60	0.67	0.70	0.80	0.77	0.75	0.69	0.66	0.60	0.61	0.58	0.62
1977	0.65	0.71	0.73	0.79	0.71	0.70	0.71	0.72	0.71	0.71	0.73	0.78
1978	0.84	0.97	1.07	1.10	1.21	1.18	1.26	1.26	1.31	1.28	1.37	1.51
1979	1.65	1.76	1.86	1.97	1.92	1.78	1.80	1.74	1.79	1.67	1.69	1.68
1980	1.72	1.80	1.57	1.44	1.44	1.53	1.52	1.53	1.49	1.47	1.41	1.43
1981	1.42	1.44	1.43	1.40	1.27	1.34	1.23	1.26	1.28	1.23	1.21	1.20
1982	1.21	1.25	1.30	1.30	1.47	1.32	1.31	1.33	1.24	1.23	1.24	1.29
1983	1.34	1.40	1.43	1.42	1.36	1.36	1.30	1.21	1.19	1.18	1.26	1.26
1984	1.28	1.35	1.32	1.30	1.25	1.22	1.28	1.28	1.22	1.25	1.26	1.26
1985	1.38	1.39	1.34	1.31	1.29	1.27	1.20	1.18	1.11	1.25	1.33	1.33

[a]Source: Florida Crop and Livestock Reporting Service (1970-1985).

TABLE 6-8. AVERAGE PRICE ($/KG) OF LIVE WEIGHT (ALL GRADES OF STOCKER HEIFERS)[a]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970	0.60	0.61	0.66	0.65	0.62	0.63	0.62	0.63	0.59	0.59	0.57	0.56
1971	0.59	0.63	0.63	0.63	0.64	0.62	0.63	0.64	0.63	0.63	0.64	0.67
1972	0.71	0.73	0.72	0.70	0.74	0.76	0.80	0.79	0.76	0.78	0.76	0.76
1973	0.86	0.93	1.02	1.01	1.02	1.00	1.04	1.13	1.00	0.91	0.83	0.83
1974	0.94	0.92	0.88	0.83	0.74	0.69	0.64	0.57	0.50	0.52	0.36	0.40
1975	0.37	0.39	0.38	0.41	0.42	0.43	0.40	0.35	0.39	0.40	0.43	0.46
1976	0.47	0.54	0.59	0.65	0.64	0.63	0.59	0.55	0.50	0.50	0.47	0.52
1977	0.54	0.57	0.63	0.65	0.60	0.58	0.59	0.59	0.59	0.57	0.60	0.65
1978	0.72	0.81	0.93	0.98	1.07	1.08	1.08	1.09	1.13	1.11	1.70	1.33
1979	1.44	1.56	1.70	1.74	1.70	1.56	1.56	1.52	1.58	1.47	1.46	1.49
1980	1.53	1.61	1.42	1.30	1.27	1.33	1.33	1.37	1.30	1.29	1.21	1.23
1981	1.24	1.26	1.26	1.23	1.14	1.19	1.11	1.12	1.12	1.05	1.04	1.06
1982	1.05	1.10	1.13	1.14	1.14	1.14	1.13	1.16	1.09	1.08	1.04	1.10
1983	1.16	1.23	1.27	1.26	1.19	1.18	1.11	1.05	1.03	1.02	1.07	1.16
1984	1.10	1.18	1.18	1.19	1.05	1.04	1.17	1.08	1.01	1.03	1.05	1.06
1985	1.38	1.39	1.34	1.31	1.29	1.27	1.20	1.18	1.11	1.25	1.33	1.33

[a] Source: Florida Crop and Livestock Reporting Service (1970-1985).

TABLE 6-9. AVERAGE PRICE ($/KG) OF LIVE WEIGHT (ALL GRADES OF COWS)[a]

Year	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1970	0.47	0.48	0.50	0.51	0.48	0.48	0.46	0.45	0.44	0.44	0.42	0.43
1971	0.45	0.49	0.50	0.48	0.49	0.49	0.48	0.47	0.46	0.47	0.48	0.48
1972	0.51	0.53	0.54	0.53	0.56	0.57	0.58	0.58	0.56	0.57	0.56	0.63
1973	0.61	0.69	0.74	0.73	0.75	0.66	0.77	0.84	0.71	0.68	0.67	0.63
1974	0.69	0.70	0.70	0.63	0.58	0.56	0.52	0.42	0.40	0.33	0.31	0.32
1975	0.32	0.34	0.33	0.33	0.34	0.35	0.29	0.28	0.28	0.30	0.32	0.34
1976	0.38	0.47	0.50	0.53	0.53	0.48	0.44	0.41	0.41	0.40	0.40	0.44
1977	0.44	0.49	0.54	0.49	0.45	0.48	0.46	0.46	0.46	0.44	0.48	0.53
1978	0.58	0.64	0.70	0.76	0.80	0.77	0.79	0.79	0.80	0.83	0.87	0.94
1979	1.05	1.20	1.21	1.29	1.28	1.24	1.23	1.11	1.11	1.09	1.09	1.15
1980	1.15	1.21	1.09	1.04	1.19	1.19	1.05	1.04	0.97	0.94	0.89	0.92
1981	0.90	0.99	0.94	0.91	0.86	0.91	0.87	0.86	0.81	0.76	0.80	0.75
1982	0.78	0.85	0.84	0.83	0.82	0.86	0.85	0.83	0.80	0.81	0.76	0.82
1983	0.82	0.87	0.90	0.88	0.88	0.82	0.78	0.74	0.72	0.72	0.72	0.73
1984	0.76	0.89	0.91	0.88	0.87	0.83	0.78	0.79	0.74	0.74	0.72	0.72
1985	0.79	0.89	0.91	0.88	0.87	0.83	0.78	0.79	0.74	0.74	0.72	0.72

[a] Source: Florida Crop and Livestock Reporting Service (1970-1985)

TABLE 6-10. INITIAL HERD COMPOSITION

Animal type	Age (years) 1	2	3	4	5	6	Total
Calving cows	-	-	72	62	54	32	231
Heifers	75	75	-	-	-	-	150
						Total	381

CHAPTER VII

RESULTS

The goal of reporting the results is two-fold; first, to demonstrate that UF COW-CALF is indeed a reliable predictive tool and secondly, to present the predicted outcome of management decisions concerning breed selection and culling policies by the use of this new tool. In order to meet the first objective, simulated herd dynamics are presented followed by a discussion of simulated growth, lactation and nutritional requirements. The effects of breed and culling policies on biological and economic aspects of the simulated cattle production are emphasized subsequently.

Simulated Herd Dynamics

As stated in Chapter II, population dynamics involve reproduction, mortality and migration contributing to the fluctuation in size and structure of a given population. In the case of a cattle herd, migration consists of the acquisition of animals from external sources, sale of feeder

calves and culling of unproductive cows. The purpose of this section is to show that the dynamics of a beef cattle herd in the system described in Chapter III can be simulated accurately according to the mathematical model discussed in Chapter III and implemented by UF COW-CALF.

The herd chosen for illustration is composed of Angus cattle. Its initial structure and composition are described in Table 6-10. The parameters of herd dynamics corresponding to Angus cattle in North Florida are shown in Table 6-6. No purchased animals are added to the herd during the fifteen years of simulated production. Historical variations in parameters that effect herd dynamics during the fifteen years are shown in Table 7-1. All culled cows are replaced with available heifers. The tendency of the rate of retention of heifers to remain high is the consequence of heavy culling. All open cows and those which lose their calves at parturition are removed from the herd in this case. The relatively high number of culled cows shown in Table 7-3 is expected since the input for pregnancy rate of Angus cattle in North Florida is relatively low. This consistency is an indication that the computer program is reliable as a predictive tool. Another way of showing that UF COW-CALF is an accurate accounting tool is to compare pregnancy rate as an input of the model (Table 6-5)

TABLE 7-1. SIMULATED[a] VARIATION OF FACTORS OF ANGUS HERD DYNAMICS.

Production Year	Calf Survival Rate (%)	Heifer Retention Rate (%)	Dead Newborn Calves	Dead Calves	Dead Cows	Culled[b] Cows
1970	97.0	37.0	6	4	3	50
1971	96.0	45.0	7	4	3	52
1972	96.0	43.0	9	6	2	49
1973	96.0	37.0	8	6	0	50
1974	96.0	53.0	9	6	0	70
1975	96.0	60.0	9	6	0	70
1976	95.0	60.0	10	4	0	69
1977	94.0	65.0	11	4	1	70
1978	94.0	66.0	12	4	1	67
1979	93.0	69.0	14	4	0	69
1980	93.0	59.0	14	4	1	60
1981	93.0	61.0	14	4	1	64
1982	93.0	58.0	15	4	1	62
1983	93.0	57.0	15	4	0	61
1984	90.0	70.0	21	4	0	80
1985	91.0	70.0	19	4	0	80

[a]Estimated from simulated dynamics of a herd of Angus cattle under heavy culling.
[b]Culled cows include open cows, cows without a calf at the end of a calving season and old cows.

TABLE 7-2. PREGNANCY RATE (%) ESTIMATED FROM SIMULATED DYNAMICS OF A HERD OF ANGUS CATTLE[a].

Production Year	Cow Age (years)							
	2	3	4	5	6	7	8	9
1970	84.0	83.0	81.0	90.0	90.0			
1971	84.0	82.0	84.0	89.0	91.0	89.0		
1972	85.0	82.0	83.0	91.0	90.0	90.0	91.0	
1973	83.0	82.0	83.0	89.0	89.0	89.0	89.0	89.0
1974	84.0	82.0	85.0	89.0	91.0	91.0	90.0	90.0
1975	85.0	83.0	83.0	91.0	91.0	90.0	90.0	88.0
1976	84.0	82.0	81.0	89.0	89.0	90.0	92.0	92.0
1977	83.0	83.0	80.0	89.0	92.0	88.0	92.0	91.0
1978	83.0	84.0	81.0	91.0	92.0	90.0	92.0	91.0
1979	84.0	83.0	81.0	91.0	90.0	90.0	89.0	91.0
1980	84.0	84.0	82.0	91.0	90.0	88.0	89.0	87.0
1981	84.0	83.0	81.0	90.0	90.0	92.0	86.0	87.0
1982	84.0	84.0	83.0	91.0	88.0	92.0	91.0	91.0
1983	83.0	84.0	81.0	91.0	89.0	91.0	91.0	89.0
1984	83.0	82.0	81.0	90.0	89.0	91.0	89.0	89.0
1985	84.0	82.0	82.0	89.0	88.0	91.0	89.0	87.0

[a]Estimated from simulated dynamics of a herd of Angus cattle under heavy culling.

TABLE 7-3. CULLED COWS IN A HERD OF ANGUS CATTLE UNDER HEAVY CULLING

Production Year	Cow Age (years)								
	2	3	4	5	6	7	8	9	10
1970	12	14	3	6	5				
1971	12	13	11	6	5	5			
1972	6	13	10	6	5	5	4		
1973	9	7	10	5	5	5	5	4	
1974	9	10	5	4	4	4	4	4	24
1975	7	10	7	3	4	4	3	4	26
1976	11	9	9	4	3	4	3	3	22
1977	12	12	7	4	3	3	3	3	22
1978	11	12	10	3	3	3	2	3	19
1979	11	12	10	5	3	3	3	2	19
1980	11	12	9	5	4	3	3	3	9
1981	11	12	11	4	4	3	3	3	12
1982	10	12	10	5	4	3	3	2	12
1983	11	11	11	5	4	3	3	3	9
1984	11	13	10	5	5	4	4	4	16
1985	10	13	10	5	5	4	4	3	15

with pregnancy rate estimated from the simulated herd dynamics (Table 7-2). It shows that heifers are bred for the first time at the age of two years. Pregnancy rates of three-year-old cows are programmed to be relatively low as a consequence of the stress from the first pregnancy and lactation.

Accuracy in implementing the mathematical model of the population dynamics can also be shown in the way the factors discussed above affect the change in composition and structure of a breeding herd. Table 7-4 shows that the ages of breeding cows range from two to six years. Total numbers of calving cows and open lactating cows during each month of the calving season are also reported. For instance, 72 cows three years of age entered the calving season at the starting year of production. At the end of the calving season, 69 cows were open and lactating and two were culled because of calf loss at parturition and one died of dystocia, presumably. The 69 open lactating cows entered the next breeding season. Fifty-seven of them became pregnant while 12 remained open and were culled. So two cows culled for loss of a calf and 12 others culled for infertility added up to 14 cows in 1970 (see Figure 7-3). The 57 pregnant cows turned four at the next calving season as shown in Table 7-5. Figure 7-1 depicts a general trend

TABLE 7-4. SIMULATED DYNAMICS OF THE POPULATION OF ANGUS COWS UNDER HEAVY CULLING[a] IN PRODUCTION YEAR ZERO.

Month	Cow Age (years)				
	2	3	4	5	6
I. Calving and open cows[b]					
Jan.		72(0)	62(0)	54(0)	43(0)
Feb.		72(31)	62(27)	54(31)	43(26)
Mar.		40(55)	34(47)	22(49)	17(40)
Apr.		16(69)	14(59)	4(52)	3(42)
II. Breeding and pregnant cows[c]					
May	75(45)	69(45)	59(38)	52(39)	42(31)
June	30(52)	24(55)	21(46)	13(47)	11(38)
July	23(63)	14(57)	13(48)	5(47)	4(38)
Aug.	(63)	(57)	(48)	(47)	(38)
Sept.	(63)	(57)	(48)	(47)	(38)
Oct.	(63)	(57)	(48)	(47)	(38)
Nov.	(63)	(57)	(48)	(47)	(38)
Dec.	(63)	(57)	(48)	(47)	(38)

[a]Heavy culling refers to culling all open cows and all cows that lose their calves at parturition. [b]Numbers in parentheses represent open lactating cows at the end of the corresponding month of calving season. [c]Numbers in parentheses represent total number of pregnant cows at the end of the corresponding month of breeding season.

TABLE 7-5. SIMULATED DYNAMICS OF THE POPULATION OF ANGUS COWS UNDER HEAVY CULLING[a] IN PRODUCTION YEAR ONE.

Month	Cow Age (years)					
	2	3	4	5	6	7
I. Calving and open cows[b]						
Jan.		63(0)	57(0)	48(0)	47(0)	38(0)
Feb.		73(27)	57(26)	48(26)	47(27)	38(23)
Mar.		35(48)	31(45)	19(45)	19(42)	15(35)
Apr.		14(60)	12(55)	4(46)	4(45)	3(37)
II. Breeding and pregnant cows[c]						
May	82(49)	60(39)	55(36)	46(34)	45(34)	37(28)
June	33(57)	21(45)	19(44)	12(41)	11(41)	9(33)
July	25(69)	13(49)	11(46)	5(41)	4(41)	4(33)
Aug.	(69)	(49)	(46)	(41)	(41)	(33)
Sept.	(69)	(49)	(46)	(41)	(41)	(33)
Oct.	(69)	(49)	(46)	(41)	(41)	(33)
Nov.	(69)	(49)	(46)	(41)	(41)	(33)
Dec.	(69)	(49)	(46)	(41)	(41)	(33)

[a]Heavy culling refers to culling all open cows and al cows that lose their calves at parturition. [b]Numbers in parentheses represent open lactating cows at the end of the corresponding month of calving season. [c]Numbers in parentheses represent total number of pregnant cows at the end of the corresponding month of breeding season.

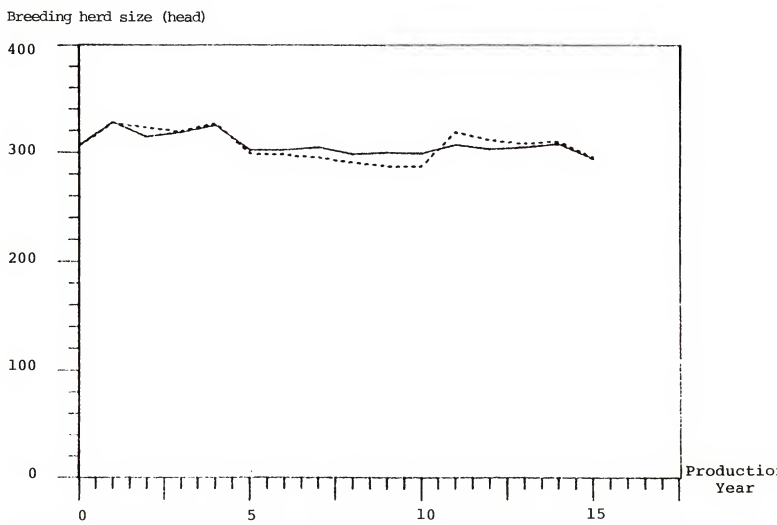


Figure 7-1. Simulated variation in the population of breeding Angus cows under heavy culling (solid line) and light culling (dotted line) in North Florida. The population comprises females of breeding age counted at the beginning of the breeding season.

in the dynamics of the population of breeding cows. This group consists of the total number of cows with ages varying from two to culling age at the beginning of a breeding season. The solid line in Figure 7-1 represents variation in the population of breeding Angus cows under heavy culling. The size fluctuates slightly at the beginning of production and stabilizes at an average size of 302 five years later. Such a trend is expected in a real cow-calf operation where farmers maintain a relatively stable herd size. Breeding herd seems to fluctuate cyclically under light culling as shown by the dotted line of Figure 7-1. The effect of culling policy on herd dynamics and the dynamics of a Brangus herd are discussed later.

Simulated Growth, Lactation and Nutritional Requirements

Growth and Lactation

The expression of cattle growth in Chapter III was developed to be mathematically and biologically coherent. It is necessary to show that its predictions are in realistic ranges. Figure 7-2 shows curves of simulated current (solid line) and theoretical (dotted line) growth of female Angus cattle using data of Table 6-5. The point I on the theoretical curve represents the inflection point which occurs at the predicted age of eight months. Over the interval birth to puberty, or ABI in Figure 7-2, growth is

described by the following expression:

$$(7\text{-}1) \quad W_n = 25.03e^{0.010(30n)}; \; 0 \leqslant n \leqslant 8.2$$

where W_n is prepubertal weight in kg at age of n months. The postpubertal theoretical weight is expressed as follows:

$$(7\text{-}2) \quad W_\theta = 425.1 - 198.18e^{-0.008(30\theta)}; \; n - 8.2 \leqslant \theta$$

where θ is the number of months after weaning. Mature weight is reached at the physiological age of 51 months or shortly after the animal has reached four years.

Portion AB of the simulated current growth is also described by equation (7-1) since B is before the inflection point. Point B corresponds to weaning. From point B to point C, i.e., from weaning to the age of two years, as indicated in Chapter VI, current weight is expressed as follows:

$$(7\text{-}3) \quad W_{\theta'} = W_{\theta'} + 6.0^{\theta'}, \; n - 7 \leqslant \theta' \leqslant 17$$

where θ' is the number of months from weaning to the age of 24 months. $W_{\theta'}$ is the body weight in kg at θ'^{th} month. The coefficient 6.0 is the product of 0.2 kg in daily gain and 30 days for a total monthly gain. This result indicates

that Angus cattle growing according to expression (7-2) between points B and C will gain more than 0.2 kg per day. From poing C to maturity, current growth is simulated according to expression (7-4):

$$(7\text{-}4) \qquad W_\theta = 425.1 - 198.18e^{-0.008\theta}, \quad 1 \leqslant \theta$$

since the weight of 272.95 kg reached at the chronological age of 24 months corresponds to a physiological age of nine months or exactly one month after puberty. This result means that the average heifer is ready for its first breeding season. A daily gain of less than 0.2 kg from weaning to 24 months of age would probably result in sexual immaturity of an Angus heifer. This finding is interesting because it must stimulate further investigations to develop sound mathematical explanations of animal growth. It is an indication that the growth model used in UF COW-CALF is consistent with at least one biological fact. According to the current growth, mature weight is reached at the age of five years. Growth above mature weight shown in Figure 7-2 is due to fat accumulation by mature cows and fetal weight during pregnancy. Figure 7-2 also shows that as a cow gets older she accumulates more fat in the case of excessive energy input.

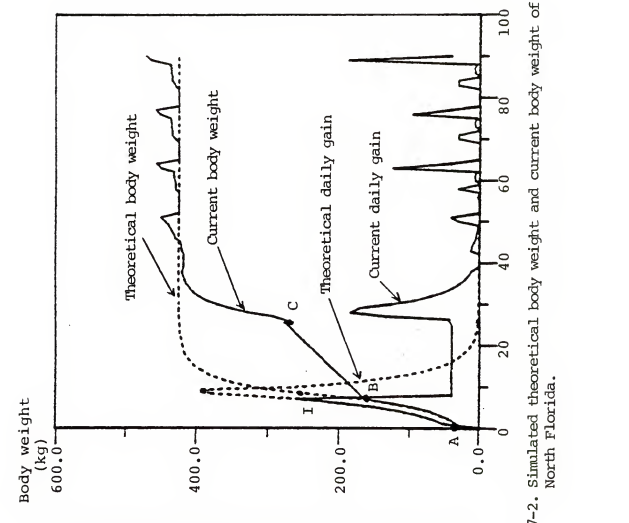


Figure 7-2. Simulated theoretical body weight and current body weight of Angus cattle in North Florida.

Figure 7-3 shows that fat accumulation corresponds to late lactation and dry period. Weight loss indicated in early lactation corresponds to fat depletion and the absence of fetal weight. A cow of five years of age and older produces more milk and maintains a high milk yield longer than a younger cow.

Net Energy and Crude Protein Requirements

The ability to estimate net energy and crude protein requirements for a herd in a cow-calf production system by means of a computer program is one major goal of the present project. This subsection is intended to demonstrate that UF COW-CALF can be used to achieve that goal.

Figure 7-4 shows the trend in variation of net energy required for maintenance and gain in relation to theoretical growth of an average female Angus cow in North Florida. Net energy for gain is based on expressions (3-46) and (3-47) derived from equation (3-3). Expressions (3-51) and (3-52) derived from (3-49) were used to estimate net energy for maintenance.

The trend in variation of crude protein required for maintenance in relation to theoretical growth of a female Angus cow in North Florida is shown in Figure 7-5. Basic equations used in this case are (3-64) and (3-65) derived from both (3-61) and (3-62). Equation (3-66) was used to

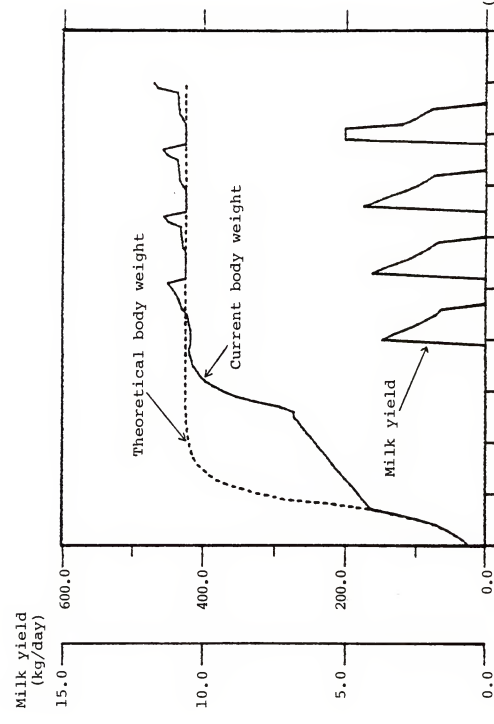


Figure 7-3. Simulated theoretical growth, current growth and lactation of an average Angus cow in North Florida.

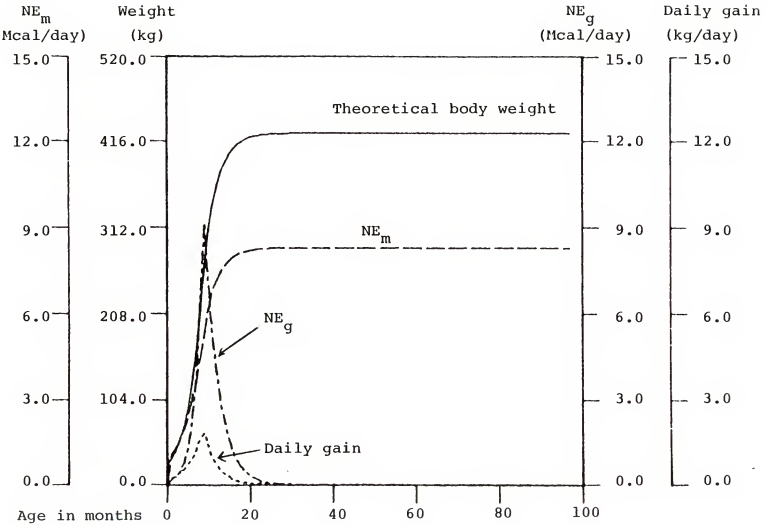


Figure 7-4. Simulated net energy requirements for gain and maintenance of the average female Angus cattle for theoretical size.

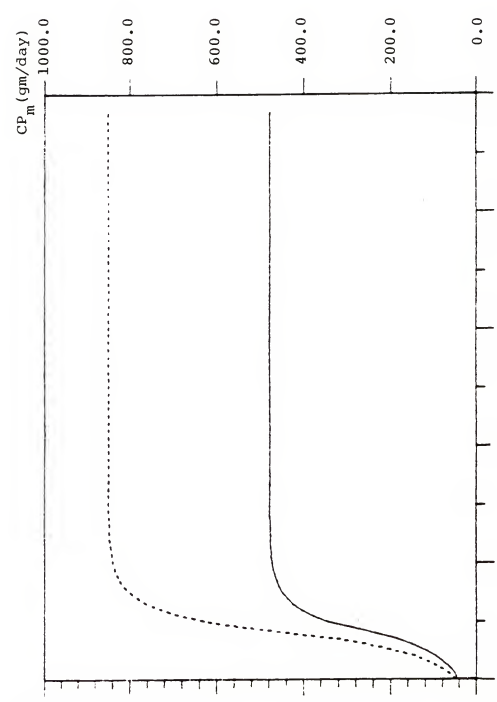


Figure 7-5. Simulated theoretical body size (dotted line) and crude protein requirement for maintenance of average Angus cattle in North Florida.

simulate crude protein required for growth. Figure 7-6 represents simulation variation in crude protein requirement for gain in relation to change in current body weight. Daily crude protein requirement for gain corresponding to linear growth is constant as expected (refer to expression 3-66).

Tables 7-6 and 7-7 are intended to demonstrate the ability to estimate nutritional requirements of beef cattle under specified conditions by the use of UF COW-CALF. Table 7-6 shows nutritional requirements of a yearling Angus heifer fed to gain at most 0.2 kg/day on a typical pasture in North Florida described in Table 6-5. Daily dry matter requirement is high in November because forage energy content is at the lowest, but relatively satisfactory, level in this month (see Table 6-5) and the animal must eat more of it in order to extract energy and crude protein in needed amounts.

Simulated nutritional requirement of an average three-year-old Angus cow in various physiological states is shown in Table 7-7. The cow represented here is an early calver which is open lactating from February to April corresponding to high milk yield. Because lactation takes priority in the use of energy, this growing cow can only eat enough to maintain weight (417.94 kg). From May to January she is

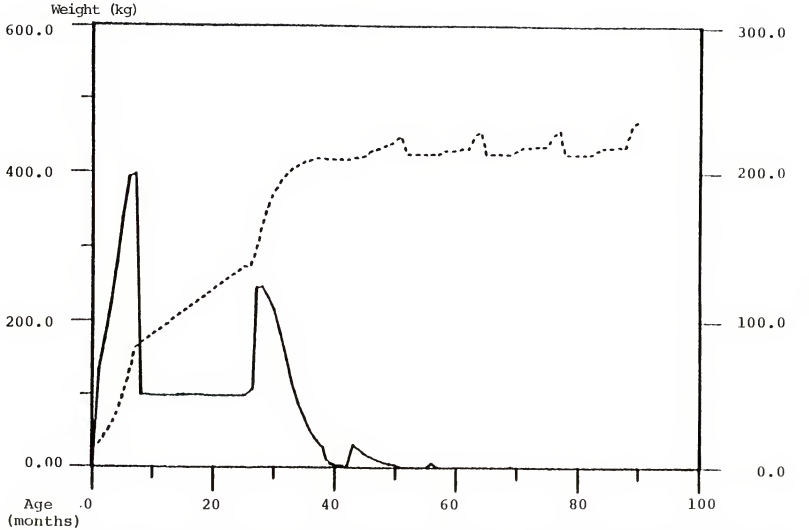


Figure 7-6. Simulated variation in crude protein requirements (solid line) for gain in relation to simulated current body weight (dotted line) of average Angus cattle in North Florida.

TABLE 7-6. SIMULATED DAILY NET ENERGY, CRUDE PROTEIN AND DRY MATTER REQUIREMENTS FOR AN AVERAGE YEARLING ANGUS HEIFER FED TO GAIN AT MOST 0.2 KG/DAY IN NORTH FLORIDA.

Month	Body Weight (kg)	Daily Gain (kg)	Feed DM (kg/day)	NE_m (Mcal/day)	NE_g (Mcal/day)	Total Crude Protein (g/day)
Feb.	206.95	0.20	4.22	4.779	0.632	305.10
Mar.	212.95	0.20	4.34	4.884	0.646	311.72
Apr.	218.95	0.20	3.71	4.988	0.660	318.19
May	224.95	0.20	4.53	5.092	0.673	324.56
June	230.95	0.20	4.84	5.195	0.687	330.86
July	236.95	0.20	5.49	5.297	0.701	337.09
Aug.	242.95	0.20	5.88	5.399	0.714	343.28
Sept.	248.95	0.20	6.00	5.499	0.727	349.43
Oct.	254.95	0.20	6.10	5.600	0.741	355.54
Nov.	260.95	0.20	6.79	5.700	0.754	361.63
Dec.	266.95	0.20	4.75	5.799	0.767	363.97
Jan.	272.95	0.20	5.04	5.897	0.780	369.99

TABLE 7-7. SIMULATED DAILY NET ENERGY, CRUDE PROTEIN, DRY MATTER, ENERGY SUPPLEMENT AND PROTEIN SUPPLEMENT REQUIREMENTS FOR A THREE-YEAR-OLD ANGUS COW IN NORTH FLORIDA.

Month	Body Weight (kg)	Daily Gain (kg)	Feed[a] DM (kg/day)	NE_m[b] (Mcal/day)	NE_g[c] (Mcal/day)	Total Crude Protein (g/day)	Energy[d] Suppl. as fed (kg/day)	Protein[e] Suppl. as fed (kg/day)
Feb.	417.94	0.00	5.05	6.992	NA	470.81	0.00	0.00
Mar.	417.94	0.00	5.03	6.992	NA	470.80	0.00	0.00
Apr.	417.94	0.00	4.30	6.992	NA	470.78	0.00	0.00
May	419.77	0.06	6.27	8.723	NA	487.39	0.00	0.00
June	421.77	0.05	6.46	8.653	NA	485.34	0.00	0.00
July	421.18	0.03	6.87	8.593	NA	483.36	0.00	0.00
Aug.	422.21	0.02	7.56	8.533	NA	481.87	0.00	0.15
Sept.	432.39	0.02	8.59	8.476	NA	484.00	0.00	0.04
Oct.	435.52	0.01	8.64	8.492	NA	484.17	0.00	0.00
Nov.	439.38	0.01	8.69	8.524	NA	484.87	0.00	0.07
Dec.	444.03	0.15	9.34	8.681	NA	575.03	0.00	0.00
Jan.	450.10	0.20	9.48	8.751	NA	578.47	0.00	0.00

[a]Total DM includes dry matter from forage, energy and protein supplements when supplementation is required. [b]NE_m includes net energy for maintenance, lactation, pregnancy and gain when these components apply. [c]NE_g is not estimated separately in case of open and lactating, pregnant and lactating and pregnant and dry cows. [d]Molasses used as energy supplement. [e]Soybean meal used as protein supplement.

pregnant and starts to gain weight as she approaches the end of lactation. Weight gain late in lactation is due to fetal growth. There is a surge in requirement for crude protein and some increase in net energy and dry matter requirements. The null requirement for energy supplement is due to two factors. One is that according to Table 6-1, forage energy content is relatively satisfactory. Secondly, since body weight is directly proportional to dry matter intake, according to expression (6-1), and because the pregnant cow is exceptionally heavy due to fetal growth, its dry matter intake is expected to be relatively high. The combination of a high forage dry matter intake with a relatively high energy content will result in a high total energy consumption. Consequently, supplementation for energy may not be necessary.

Protein supplement is required in August, September and November, which correspond to low concentration of protein in available forage (see Table 6-1). Requirement for dry matter is lowest in April when forage quality is the highest in terms of crude protein net energy content (see Table 6-1). These nutritional recommendations demonstrate the ability of UF COW-CALF to provide flexible and accurate tables of nutrient requirements for ration formulation. Requirements for minerals and vitamins should be included in

the model in future versions of UF COW-CALF in order to make it more complete.

Simulated Economics of Cow-Calf Production in North Florida by Means of UF COW-CALF

This section further demonstrates that UF COW-CALF can be used to implement all the management options described in Chapter IV. A herd of Angus cattle under heavy culling is used as an example as in the previous discussions of this chapter.

Table 7-8 shows the simulated use of important factors of production from 1970 to 1985. The size of the breeding herd is estimated at the beginning of the breeding season, or in May in this case, and it includes all females of breeding age. Land requirement is based on forage consumption in May by breeding females, suckling calves and yearling heifers, pasture dry matter yield (272.15 kg/acre) in May and the average percentage (45%) of the total available forage dry matter consumed in the same month. The beginning of the breeding season is chosen because it marks the time when most of animals that constitute the herd are present. Stocking rate is inversely proportional to the forage dry matter yield and is a reflection of forage quality described in Table 6-1. Labor requirement depends on the rate of labor use per kg of beef sold. In general,

TABLE 7-8. SIMULATED USE OF IMPORTANT FACTORS OF COW-CALF PRODUCTION WITH A HERD OF ANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Breeding Herd[a] (# cows)	Land[a] (acres)	Labor[a] (hours)	Fertilizer[a] (metric tons)	Energy Suppl. as fed(kg)	Protein Suppl. as fed(kg
1970	306	464.30(0.88)[b]	2,266.94(.04)[b]	21.06	27,342.00	4,045.94
1971	328	458.09(0.80)	2,351.96(.04)	20.77	25,814.00	3,921.65
1972	314	482.35(0.84)	2,400.23(.04)	21.87	18,256.00	5,360.00
1973	318	480.61(0.84)	2,443.32(.04)	21.80	21,332.00	5,115.00
1974	325	477.26(0.82)	2,216.17(.04)	21.64	22,649.00	5,257.00
1975	302	476.30(0.87)	2,032.21(.04)	21.60	21,897.00	5,047.00
1976	302	456.22(0.88)	1,933.54(.04)	20.69	27,444.00	4,566.00
1977	305	448.75(0.86)	1,906.21(.04)	20.35	27,861.00	4,581.00
1978	298	449.48(0.87)	981.01(.02)	20.38	26,430.00	4,380.00
1979	300	444.69(0.87)	967.06(.02)	20.17	27,941.00	3,192.00
1980	299	444.24(0.87)	1,016.49(.02)	20.15	27,237.00	4,373.00
1981	307	446.35(0.85)	1,031.50(.02)	20.24	27,165.00	4,569.69
1982	303	451.10(0.86)	1,029.31(.02)	20.47	25,258.00	4,634.00
1983	305	448.99(0.86)	1,041.30(.02)	20.38	26,044.00	4,599.00
1984	308	442.36(0.84)	989.75(.02)	20.00	26,425.00	4,609.00
1985	308	442.36(.084)	946.77(.02)	20.06	26,235.00	4,446.00

[a]Refer to text for explanations on estimations of these factors. [b]Numbers in parentheses are stocking rates in acres/head. [c] Numbers in parentheses are rate of labor requirement in h/kg of beef sold (Agricultural Statistice, USDA).

years of low labor requirement correspond to years of sales of a small number of animals (see tables 7-8 and 7-10). Fertilizer requirement estimates are based on the application rate of 45.35 kg, or 100 lbs, per acre. Following high levels in the first five years, land requirement stabilizes at the average of 446 acres supporting 302 cows and corresponding to the use of 20.30 metric tons of fertilizer. These results reflect the realities of beef cattle farming in general as the acreage needs of farmers do not vary on a yearly basis. Energy supplement is required by growing animals after weaning. The need to use protein supplement is an indication that forage is essentially low in protein in North Florida as shown in Table 6-1.

Table 7-9 shows simulated costs of major factors of beef cattle production in a cow-calf operation with a herd of Angus cattle under heavy culling. In general, total costs of factors of production shown in Table 7-8 increased substantially from 1970 to 1985 corresponding to the same trend in variation of their prices reported in Table 6-10. For instance total cost of fertilizer varied from $1,221.50 in 1970 to $3,446.71 in 1985, even though its total use remained relatively constant over the same period. The cost of borrowing money also increased remarkably from 1970 to 1985. The increase in labor cost was more moderate.

TABLE 7-9. SIMULATED COSTS ($) OF MAJOR FACTORS OF PRODUCTION WITH A HERD OF ANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Labor	Fertilizer	Energy Supplement	Protein Supplement	Paid Interest	Total Expenses
1970	3,717.78	1,221.50	0.00	558.25	445.12	7,989.52
1971	4,068.89	1,267.49	0.00	616.89	500.13	9,123.09
1972	4,416.43	1,378.37	1,105.93	771.83	635.28	11,223.37
1973	4,886.64	1,678.60	1,763.62	1,571.08	789.88	13,738.77
1974	4,609.63	2,706.03	2,221.74	1,191.94	900.23	14,540.01
1975	4,592.79	3,456.71	2,044.00	985.42	943.96	14,624.53
1976	4,775.85	2,897.10	2,644.35	1,074.86	908.51	15,561.86
1977	5,052.46	2,747.92	2,911.60	1,299.09	1,129.34	16,599.73
1978	2,786.08	3,037.81	2,919.57	1,175.35	999.61	14,692.88
1979	3,162.28	3,186.99	3,747.11	1,284.82	1,189.99	16,644.40
1980	3,049.46	4,292.02	4,288.16	1,335.77	1,500.50	18,747.69
1981	3,991.90	4,332.68	4,648.15	1,486.15	1,605.50	20,274.07
1982	3,952.54	4,419.64	4,070.05	1,374.02	1,723.21	19,673.30
1983	3,967.34	4,439.70	4,176.51	1,443.65	1,806.67	20,058.11
1984	3,761.05	4,414.26	4,191.68	1,346.35	1,743.13	19,530.18
1985	3,597.73	4,451.31	3,171.44	1,000.95	1,290.38	17,420.16

Sales of steers, heifers and culled cows are reported in Table 7-10. More steers are sold than heifers because heavy culling required a high heifer retention rate (Table 7-1) to replace breeding cows eliminated from the herd. Steers and heifers are sold at weaning weights of 173.57 kg (382.6 lb) and 163.34 kg (360.1 lb), respectively. Total revenue and net revenue varied widely from 1970 to 1981 and became stable afterwards (Table 7-10 and Figure 7-7). This trend was similar to that of beef prices over the same period according to Tables 6-7, 6-8 and 6-9. Many other production costs may be omitted in this study but they can be easily incorporated in the model in future research projects that require the use of UF COW-CALF.

Effects of Culling Policy and Breed on Herd Dynamics, Growth and Lactation, Nutritional Requirements and Net Revenue

Thus far, all efforts have been devoted to demonstrating the usefulness and reliability of UF COW-CALF as a research and management tool. Since that objective has been accomplished, the next relevant step is to report the results of the first application of UF COW-CALF to study the effects of culling policy and cattle breed on herd dynamics, growth and lactation, nutritional requirements and net revenue.

TABLE 7-10. SIMULATED SALES OF STEERS, HEIFERS AND COWS FROM A HERD OF ANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Steers (head)	Heifers (head)	Cows[a] (head)	Total Revenue ($)	Net Revenue ($)
1970	111	69	50	28,823.95	20,834.43
1971	121	67	52	30,728.51	21,605.42
1972	131	75	49	39,436.81	28,213.45
1973	128	79	50	59,880.95	46,142.17
1974	128	62	70	31,694.97	17,154.96
1975	122	49	70	21,080.43	6,455.90
1976	110	44	69	29,814.14	14,252.28
1977	109	39	60	31,152.32	14,552.59
1978	110	36	67	52,748.14	38,055.26
1979	108	32	69	73,923.48	57,279.09
1980	106	44	60	63,324.21	45,576.52
1981	109	42	64	55,032.35	34,758.28
1982	111	47	62	56,286.82	36,613.52
1983	110	46	61	51,676.15	31,618.04
1984	110	33	70	55,511.68	35,981.50
1985	104	31	70	51,334.13	33,913.97

[a]Sold cows include all open cows, cows which lose their calves at parturition and old cows.

The format of this section is related to the four scenarios described briefly at the end of Chapter VI. Scenario one, which consists of a commercial cow-calf production with a herd of Angus cattle under heavy culling, has been used as an example in previous discussions of this chapter. It is therefore convenient to summarize it in order to facilitate understanding of comparisons with other scenarios.

Angus cattle raised in North Florida showed a relatively low pregnancy rate, requiring high heifer retention in order to replace culled open cows. Breeding herd size fluctuated moderately during the first six years of production before reaching some equilibrium (see Figure 7-1). The reason for an increase in the breeding herd size from year zero to year one of production was that many heifers (see Table 6-10) of breeding age were present in the initial herd. Female Angus cattle growing theoretically according to expressions (7-1) and (7-2) reached mature weight at the physiological age of four years and at a chronological age of five years under the North Florida conditions described in Chaper VI. Under these conditions, Angus steers and heifers weaned at seven months of age weighed 173.57 kg (382.6 lb) and 163.34 kg (360.1 lb), respectively. A breeding herd of Angus cattle under heavy

culling and at the equilibrium size of 302 cows, required 446 acres of land producing 272.15 kg of forage dry matter per acre in May if total forage consumption by the herd represents 45 percent of total forage available in the same month. Due to the low pregnancy rate mentioned earlier, culled cows constituted a considerable percentage of animals sold each year. Total revenues and net revenues were reflections of not only the weights of animals sold, but also of beef prices and input cost.

Scenario 2.

Scenario two consists of studying cow-calf production in North Florida with a herd of Angus cattle under light culling. The discussion of this case concerns herd dynamics and its effect on the use of beef cattle production factors, cost of production, total revenues and net revenues. In terms of herd dynamics, only factors such as heifer retention rate and number of cows culled which are likely to be affected by a culling policy are discussed. Mortality remains essentially the same since the same breed is under study.

According to Tables 7-1 and 7-11, variations in heifer retention rate and number of culled cows are greater under light culling than heavy culling. From 1970 to 1975, most culled cows are those open in two consecutive years (see

TABLE 7-11. SIMULATED HEIFER RETENTION RATES AND CULLED COWS IN A HERD OF ANGUS CATTLE UNDER LIGHT CULLING.

	Production Year															
	1970	71	72	73	74	75	76	77	78	79	80	81	82	83	83	85
Heifer Retention Rate (%)	8.0	11.0	13.0	14.0	37.0	45.0	51.0	55.0	58.0	59.0	24.0	26.0	29.0	29.0	45.0	51.0
Culled Cows[a]	6	10	14	17	50	55	55	59	60	57	22	26	29	33	51	54

[a] Culled cows include old cows, cows open in two consecutive breeding seasons and cows without a calf at the end of a calving season.

Table 7-11). From 1975 to 1979, most culled cows are old ones retained in the herd in previous years. Fewer cows are culled between 1980 and 1983, because fewer old cows are present and fewer younger cows are open in two consecutive years. It was assumed earlier in the model that growing cows open at one breeding season are likely to become pregnant at the next breeding season. The variation of breeding herd size under light culling (Figure 7-1) reflects directly the trend in the changes of heifer retention rate and number of culled cows.

The economics of light culling are likely to be different from the economics of heavy culling. Land requirement is greater under light culling since breeding herd size remains generally higher with the retention of open cows. Consequently there is a greater need for fertilizer, labor and protein supplement as shown in Table 7-12, with the rise in the use of factors of production, their costs increased according to Table 7-13, as expected. However, requirement for energy supplement is an exception to the above conclusion. The percentage of growing animals is higher in a herd under heavy culling than one under light culling. Since energy supplement is required almost exclusively by growing animals, its use is expected to be greater under heavy culling than light culling (see Tables

TABLE 7-12. SIMULATED USE OF IMPORTANT FACTORS OF COW-CALF PRODUCTION WITH A HERD OF ANGUS CATTLE UNDER LIGHT CULLING.

Production Year	Breeding Herd (# cows)	Land[a] (acres)	Labor (hours)	Fertilizer (metric tons)	Energy Suppl. as fed(kg)	Protein Suppl. as fed(kg
1970	306	464.30(0.88)	1,655.81(.04)	21.07	27,481.00	4,595.00
1971	328	487.19(0.85)	1,855.91(.04)	22.11	22,964.00	7,377.00
1972	323	563.30(0.86)	2,255.33(.04)	25.57	4,844.00	7,422.00
1973	320	532.08(0.87)	2,274.19(.04)	24.15	5,385.95	8,440.93
1974	328	525.02(0.84)	2,004.95(.04)	23.83	11,021.39	7,250.26
1975	299	513.40(0.92)	1,719.90(.04)	23.30	13,495.66	9,830.74
1976	298	481.90(0.91)	1,448.59(.04)	21.87	21,738.13	4,112.04
1977	296	476.10(0.92)	1,906.21(.04)	21.61	24,567.84	5,344.29
1978	291	474.31(0.93)	1,376.10(.04)	21.53	19,124.31	4,310.51
1979	288	469.98(0.95)	703.14(.02)	21.33	22,930.21	4,481.35
1980	287	471.01(0.95)	649.94(.02)	21.38	22,795.03	4,240.86
1981	319	479.75(0.86)	804.43(.02)	21.77	22,431.03	5,722.44
1982	312	504.21(0.88)	887.13(.02)	22.91	11,484.85	5,420.56
1983	309	499.88(0.88)	973.05(.02)	22.69	13,561.00	5,965.09
1984	311	493.18(0.88)	845.05(.02)	22.38	17,120.45	7,021.24
1985	297	477.64(0.91)	742.94(.02)	21.68	18,519.00	6,262.00

[a]Numbers in parentheses represent stocking rates in acres/head.

TABLE 7-13. SIMULATED COSTS ($) OF MAJOR FACTORS OF PRODUCTION WITH A HERD OF ANGUS CATTLE UNDER LIGHT CULLING.

Production Year	Labor	Fertilizer	Energy Supplement	Protein Supplement	Paid Interest	Total Expenses
1970	2,715.54	1,221.50	0.00	576.71	387.08	6,947.70
1971	3,210.72	1,303.20	0.00	653.35	469.77	8,569.32
1972	4,149.80	1,532.53	290.74	923.28	617.00	10,900.37
1973	4,518.38	1,858.37	533.21	1,915.67	748.98	13,027.31
1974	4,170.99	2,976.80	1,024.99	1,413.15	837.87	13,532.90
1975	3,886.98	3,725.98	1,275.34	1,102.42	874.25	13,544.57
1976	3,578.00	3,060.19	2,266.20	1,167.45	826.65	14,159.69
1977	3,646.66	2,915.38	2,598.05	1,368.85	1,016.63	14,943.04
1978	1,996.93	3,205.59	2,781.38	1,231.47	944.11	13,877.18
1979	2,125.31	3,368.23	3,525.52	1,352.07	1,106.34	15,474.40
1980	2,413.30	4,550.60	3,775.99	1,381.42	1,460.93	18,253.27
1981	3,433.20	4,655.86	3,600.18	1,695.96	1,577.83	19,924.63
1982	3,736.50	4,949.82	1,843.32	1,702.98	1,645.68	18,662.56
1983	3,654.15	4,942.97	2,166.37	1,746.64	1,702.82	18,902.97
1984	3,211.18	4,921.44	2,619.43	1,599.72	1,639.16	18,365.29
1985	2,823.16	4,802.73	2,211.99	1,147.07	1,205.25	16,270.91

7-8 and 7-12). A corollary to higher feed supplementation is the slightly higher total expense noticed by comparing Tables 7-9 and 7-13.

More calves are sold under light culling than under heavy culling (see Tables 7-10 and 7-14). The explanation of this prediction is that, under light culling, more cows are present to produce more calves, and more heifers are available for sale since only a few are retained for replacement. In 1970 and 1971, total revenues and net revenues are higher under heavy culling than under light culling due to the sale of more cows in the first case (see Figure 7-7 and Tables 7-10 and 7-14). The opposite is true from 1972 to 1978, when higher numbers of calves and an increasing number of old cows were sold under light culling. From 1979 to 1983 revenues are less under light culling because more old cows are culled leaving less females of breeding age that produce less calves for sale. Most heifers that are produced are not for sale since they must be retained to replace old cows. In conclusion, a young breeding herd will produce more favorable net revenues under light culling than under heavy culling. An older breeding herd will produce less revenues under light culling. A higher percentage of young cows and old cows alternate cyclically under light culling while under heavy culling a

TABLE 7-14. SIMULATED SALES OF STEERS, HEIFERS AND COWS FROM A HERD OF ANGUS CATTLE UNDER LIGHT CULLING.

Production Year	Steers (head)	Heifers (head)	Cows (head)	Total Revenue ($)	Net Revenue ($)
1970	111	101	6	23,824.84	16,877.14
1971	121	109	10	26,871.80	18,302.48
1972	150	131	14	40,685.60	29,785.23
1973	147	126	19	60,957.03	47,929.72
1974	147	93	52	33,218.88	19,685.98
1975	132	71	57	21,469.21	7,924.64
1976	116	55	55	29,058.58	14,898.89
1977	111	51	59	30,644.10	15,701.06
1978	110	45	60	52,353.39	38,476.20
1979	106	41	67	70,361.69	54,887.29
1980	106	80	22	55,829.28	37,576.02
1981	120	86	26	51,851.76	31,927.13
1982	131	96	31	59,454.66	40,792.10
1983	129	92	33	54,676.74	35,773.77
1984	126	69	51	58,204.81	39,839.52
1985	114	56	54	53,269.92	36,999.01

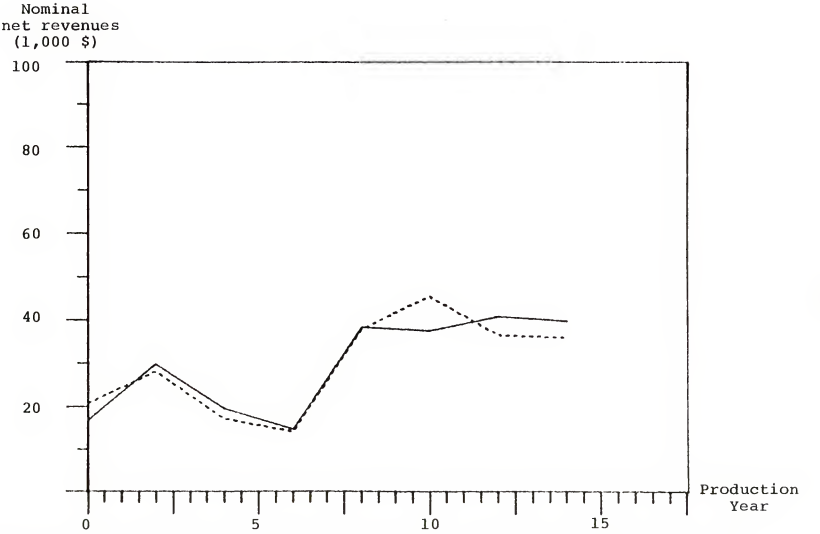


Figure 7-7. Simulated variation in nominal net revenues in a beef cattle production involving a herd of Angus cattle under light culling (solid line) and heavy Culling (dotted line).

higher percentage of younger cows is consistent over the fifteen years of production (refer to Tables A1 and A2).

Scenario 3.

The simulated cow-calf production in scenario 3 is based on a herd of Brangus cattle and the elimination of all cows that fail to conceive for the first time. Initial herd composition is the same as in scenarios 1 and 2. Elements of herd dynamics such as pregnancy and mortality shown in Table 7-15 are characteristic of Brangus cattle and therefore different from those of the Angus breed. According to Tables 7-1 and 7-15, calf survival rate is lower in a Brangus herd than in an Angus herd. In general, mortality is higher in Brangus than in Angus cattle, which is a reflection of input data shown in Table 6-5. Cows without a calf at the end of calving season constitute a high percentage of culled Brangus cows. One economic advantage of raising Brangus cattle over Angus cattle is the higher pregnancy rate of the former which compensates for its lower calf survival rate as demonstrated by the number of calves sold when these two breeds are under the same culling policy (see Tables 7-2, 7-10, 7-16 and 7-20). It is important to remember that these results are related to input data on reproduction and mortality.

TABLE 7-15. SIMULATED[a] VARIATION OF FACTORS OF BRANGUS HERD DYNAMICS.

Production Year	Calf Survival Rate (%)	Heifer Retention Rate (%)	Dead Newborn Calves	Dead Calves	Dead Cows	Culled[b] Cows
1970	93.0	43.0	14	2	3	54
1971	93.0	53.0	16	4	3	57
1972	94.0	49.0	15	4	1	55
1973	93.0	44.0	15	4	0	54
1974	93.0	61.0	17	4	0	74
1975	92.0	64.0	18	4	0	73
1976	91.0	64.0	18	2	0	70
1977	92.0	65.0	16	3	1	70
1978	93.0	65.0	17	3	1	68
1979	92.0	62.0	16	3	0	66
1980	92.0	58.0	16	3	1	62
1981	92.0	60.0	16	4	1	63
1982	92.0	58.0	17	4	0	64
1983	92.0	57.0	18	4	0	64
1984	92.0	61.0	17	4	0	67
1985	92.0	61.0	17	4	0	66

[a]Estimated from simulated dynamics of a herd of Brangus cattle under heavy culling.
[b]Culled cows include open cows, cows without a calf at the end of a calving season and old cows.

TABLE 7-16. PREGNANCY RATE (%) ESTIMATED FROM SIMULATED DYNAMICS OF A HERD OF BRANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Cow Age (years)							
	2	3	4	5	6	7	8	9
1970	85.0	83.0	84.0	90.0	90.0			
1971	85.0	83.0	84.0	91.0	90.0	89.0		
1972	84.0	83.0	83.0	90.0	89.0	90.0	90.0	
1973	85.0	84.0	83.0	89.0	89.0	91.0	90.0	92.0
1974	85.0	83.0	83.0	89.0	90.0	90.0	89.0	92.0
1975	84.0	83.0	84.0	91.0	91.0	92.0	92.0	91.0
1976	85.0	85.0	84.0	90.0	89.0	92.0	90.0	90.0
1977	84.0	84.0	85.0	90.0	92.0	87.0	90.0	88.0
1978	84.0	84.0	83.0	88.0	92.0	90.0	92.0	88.0
1979	85.0	85.0	84.0	89.0	90.0	90.0	88.0	90.0
1980	85.0	85.0	83.0	89.0	90.0	88.0	88.0	86.0
1981	85.0	85.0	84.0	91.0	90.0	92.0	86.0	86.0
1982	84.0	85.0	84.0	89.0	89.0	92.0	90.0	91.0
1983	85.0	84.0	85.0	90.0	91.0	90.0	90.0	88.0
1984	85.0	84.0	85.0	91.0	90.0	92.0	89.0	88.0
1985	86.0	84.0	85.0	90.0	89.0	92.0	90.0	88.0

The general effect of heavy culling on variation of the population of breeding Brangus cows is shown in Figure 7-8 is characterized by less fluctuation and a higher percentage of young cows as in scenario one. Under heavy culling the simulated size of breeding herd remains slightly higher with Angus cattle than with Brangus cattle in general as shown in Figure 7-9. This difference is due to the differences in mortality and reproduction (see Tables 7-1, 7-2, 7-15 and 7-14).

Theoretically, female Brangus cattle grow according to the following expression:

$$(7\text{-}5) \quad W_n = 28.71e^{0.011(30n)};\ 0 \leqslant n \leqslant 8.4$$

where W_n is prepubertal weight in kg at age n in months. The expression for postpubertal growth is as follows:

$$(7\text{-}6) \quad W_\theta = 493.75 - 220.01e^{-0.0089(30\theta)},\ n - 8.4 \leqslant \theta$$

where θ is as explained earlier. Mature weight is reached at the physiological age of four years as in Angus cattle. Growing according to expression (7-5) from birth to weaning, at a daily gain of 0.2 kg from weaning to the age of two and according to expression (7-6) from the age of two to maturity, female Brangus cattle reached mature weight at the

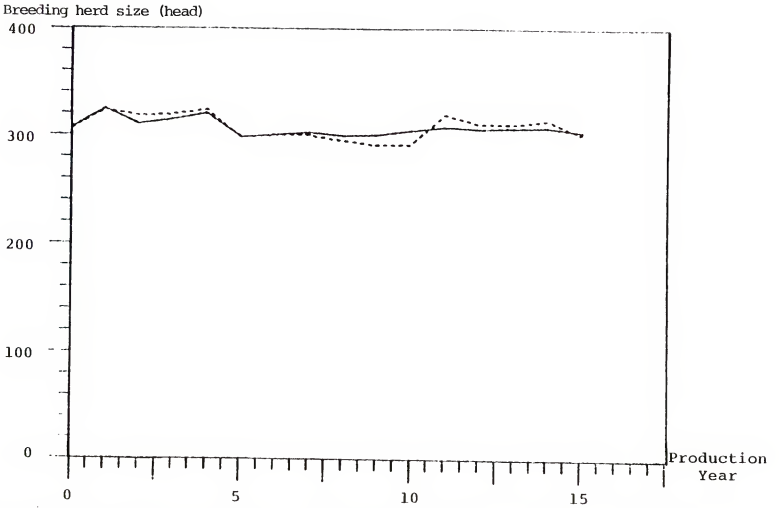


Figure 7-8. Simulated variation in the population of breeding Brangus cows under heavy culling (solid line) and light culling (dotted line).

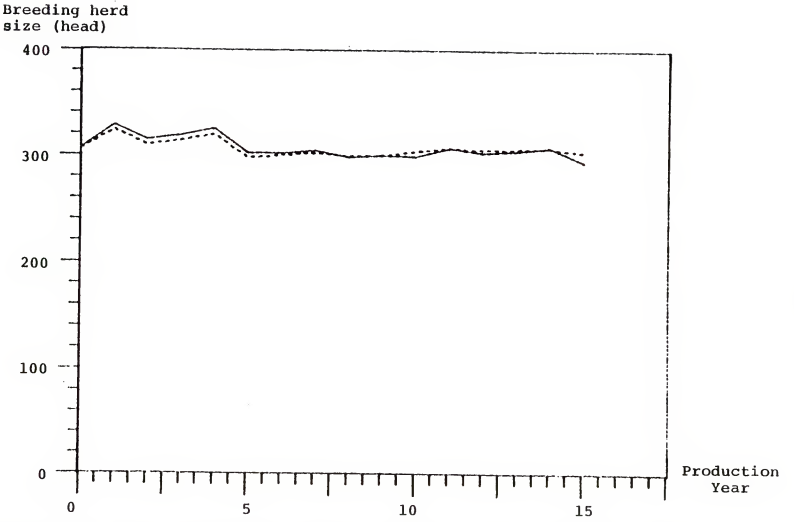


Figure 7-9. Simulated variation in the population of breeding Angus cows (solid line) and Brangus cows (dotted line) under heavy culling.

same chronological age of five years as Angus cattle. Theoretical weight and current growth of Brangus cattle raised under the conditions described in Chapter VI are shown in Figure 7-10. Comparative theoretical growth of Angus and Brangus cattle are shown in Figure 7-11. According to expressions (7-1) and (7-5), Brangus cattle should grow faster than Angus cattle which is confirmed by data presented in Table 7-17. Daily gain as a breed characteristic under optimal feeding conditions is important for its effect on nutritional requirement and net revenues.

Simulated use of important factors of cow-calf production with a herd of Brangus cattle under heavy culling is presented in Table 7-18. According to Table 7-7 and 7-18, raising Brangus cattle requires more resources than raising Angus cattle with approximately the same breeding herd size under heavy culling. A comparison of data in Table 7-12 and those in Table 7-18 show that Angus cattle under light culling necessitate use of less resources than Brangus cattle under heavy culling. These results indicate that, individually, Brangus cattle are more expensive to raise than Angus cattle.

Table 7-19 shows that high use of resources with a Brangus herd is translated into high cost of production. Under heavy culling, total expenses of raising Brangus

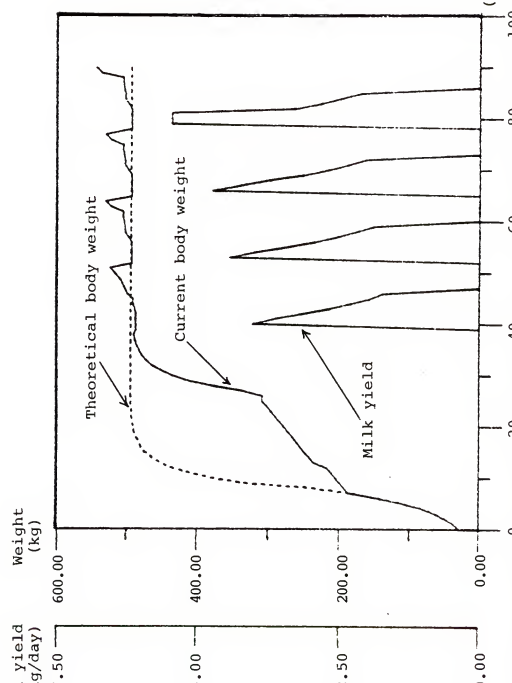


Figure 7-10. Simulated theoretical body weight, current body weight and lactation of an average Brangus female cattle in North Florida.

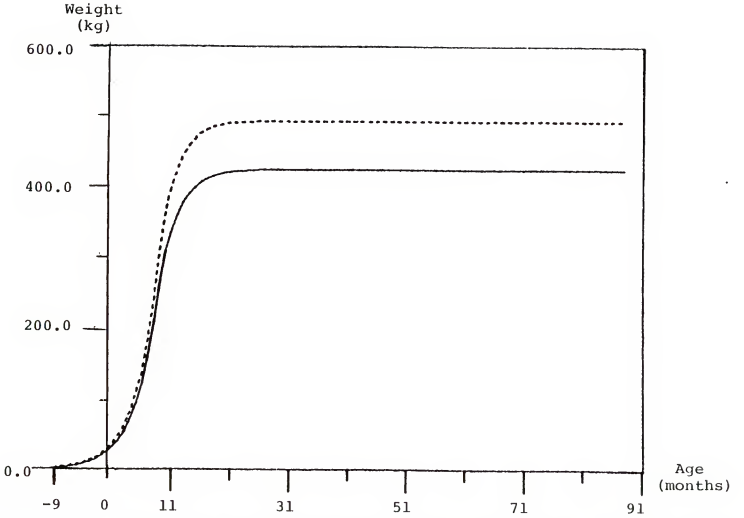


Figure 7-11. Comparative theoretical body weights of Angus (solid line) and Brangus (dotted line) cattle from conception to maturity.

TABLE 7-17. SIMULATED DAILY NET ENERGY, CRUDE PROTEIN AND DRY MATTER REQUIREMENTS FOR AVERAGE ANGUS AND BRANGUS FEMALE CALVES FROM BIRTH TO WEANING.

Month	Breed[a]	Body Weight (kg)	Daily Gain (kg)	Feed DM (kg/day)	NEm (Mcal/day)	NEg (Mcal/day)	Total Crude Protein (g/day)
Jan.[b]	AA	25.030	0.00	0.00	0.00	0.00	0.00
	AB	28.710	0.00	0.00	0.00	0.00	0.00
Feb.	AA	32.722	0.256	0.00	1.101	0.189	102.990
	AB	37.536	0.294	0.00	1.221	0.242	116.296
Mar.	AA	42.778	0.335	0.00	1.346	0.307	130.388
	AB	49.076	0.385	0.00	1.492	0.395	146.896
Apr.	AA	55.924	0.438	0.862	1.646	0.501	164.178
	AB	64.163	0.503	1.085	1.825	0.646	184.151
May	AA	73.109	0.573	1.422	2.012	0.824	204.600
	AB	83.889	0.658	1.764	2.231	1.066	227.559
June	AA	95.576	0.749	2.233	2.460	1.363	249.992
	AB	109.678	0.860	2.836	2.728	1.771	273.456
July	AA	124.948	0.979	3.232	3.008	2.274	293.718
	AB	143.396	1.124	3.584	3.335	2.972	310.249
Aug.	AA	163.345	1.280	3.790	3.678	3.837	316.820
	AB	187.480	1.469	4.203	4.078	5.047	329.755

[a]AA designates Angus and AB designates Brangus. [b]Data estimated at the end of corresponding month.

TABLE 7-18. SIMULATED USE OF MAJOR FACTORS OF COW-CALF PRODUCTION WITH A HERD OF BRANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Breeding Herd (# cows)	Land[a] (acres)	Labor (hours)	Fertilizer (metric tons)	Energy Suppl. as fed(kg)	Protein Suppl. as fed(kg)
1970	306	515.28(0.99)	2,409.57	23.29	38,589.00	5,792.00
1971	324	506.26(0.92)	2,445.49	22.98	37,370.00	6,214.00
1972	310	535.49(0.96)	2,587.11	24.30	27,277.00	6,634.00
1973	314	528.36(0.96)	2,560.99	23.98	32,058.00	6,173.00
1974	320	424.03(0.94)	2,350.20	23.85	33,151.00	6,517.00
1975	298	520.88(1.00)	2,133.93	23.64	31,693.00	6,182.00
1976	301	501.00(0.98)	2,054.76	22.74	39,648.00	5,682.00
1977	303	503.01(0.97)	2,118.67	22.83	38.387.00	5,825.00
1978	300	505.37(0.98)	1,131.64	22.94	36,984.00	5,837.00
1979	301	506.82(0.98)	1,128.52	23.00	37,812.00	5,842.00
1980	305	506.45(0.97)	1,170.66	22.99	37,263.00	5,909.00
1981	308	512.21(0.97)	1,178.28	23.25	35,627.00	6,081.00
1982	306	514.70(0.97)	1,180.46	23.36	34,635.00	5,923.00
1983	307	511.62(0.97)	1,182.26	23.22	35,271.00	6,076.00
1984	308	512.28(0.97)	1,157.21	23.25	35,427.00	6,107.00
1985	304	512.34(0.98)	1,131.27	23.25	34,953.00	6,067.00

[a]Numbers in parentheses are stocking rates in acres/head.

TABLE 7-19. SIMULATED COSTS ($) OF MAJOR FACTORS OF PRODUCTION WITH A HERD OF BRANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Labor	Fertilizer	Energy Supplement	Protein Supplement	Paid Interest	Total Expenses
1970	3,951.70	1,355.60	0.00	711.33	472.61	8,482.99
1971	4,230.70	1,400.76	0.00	774.72	522.76	9,535.86
1972	4,760.28	1,530.22	1,625.68	963.34	702.51	12,410.93
1973	5,121.98	1,845.39	2,621.84	1,952.73	883.44	15,366.15
1974	4,888.41	2,978.88	3,256.94	1,477.71	1,017.90	16,440.58
1975	4,822.69	3,780.28	2,956.37	1,206.76	1,055.67	16,355.21
1976	5,075.26	3,181.49	3,802.98	1,337.17	1,029.06	17,626.75
1977	5,614.47	3,080.19	4,041.43	1,650.35	1,300.95	19,122.17
1978	3,213.86	3,415.56	4,045.67	1,506.50	1,166.86	17,151.29
1979	3,690.27	3,632.23	5,041.81	1,669.87	1,398.97	19,567.38
1980	3,511.97	4,893.07	5,832.31	1,783.56	1,773.11	22,153.65
1981	4,559.93	4,971.93	6,107.96	1,979.19	1,877.21	23,705.21
1982	4,532.96	5,042.81	5,448.92	1,810.81	2,027.95	23,152.38
1983	4,504.41	5,059.02	5,657.16	1,901.05	2,111.73	23,442.38
1984	4,397.39	5,112.01	5,625.34	1,784.96	2,066.19	23,149.80
1985	4,298.82	5,159.11	4,526.20	1,371.52	1,556.75	21,016.18

cattle are approximately 18 percent higher than those of Angus according to Tables 7-9 and 7-19. The cost of raising Brangus cattle under heavy culling remains the highest so far (see Tables 7-9, 7-13 and 7-19).

Table 7-20 shows that despite higher resource requirements and higher expenses involved in raising Brangus cattle, resulting net revenues are higher than those obtained with Angus cattle under heavy and light culling (see Tables 7-10, 7-14 and 7-20). This difference is explained by the fact that Brangus cattle have heavier market weights than Angus cattle. For example, Brangus steers and heifers are sold at weaning weights of 199.07 kg (438.8 lb) and 187.48 kg (413.3 lb), respectively. In contrast, Angus steers and heifers weigh only 173.56 kg (382.6 lb) and 163.34 kg (360.1 lb), respectively, at weaning.

Scenario 4.

A herd of Brangus cattle under light culling constitutes the basis of scenario four. The points of interest are effects of light culling on population dynamics, herd nutritional requirements, cost of production and net revenues.

According to Table 7-21, heifer retention rate varies cyclically and proportionally with number of culled cows,

TABLE 7-20. SIMULATED SALES OF STEERS, HEIFERS AND COWS FROM A HERD OF BRANGUS CATTLE UNDER HEAVY CULLING.

Production Year	Steers (head)	Heifers (head)	Cows (head)	Total Revenue ($)	Net Revenue ($)
1970	111	101	6	23,824.84	16,877.14
1971	121	109	10	26,871.80	18,302.48
1972	150	131	14	40,685.60	29,785.23
1973	147	126	19	60,957.03	47,929.72
1974	147	93	52	33,218.88	19,685.98
1975	132	71	57	21,469.21	7,924.64
1976	116	55	55	29,058.58	14,898.89
1977	111	51	59	30,644.10	15,701.06
1978	110	45	60	52,353.39	38,476.20
1979	106	41	67	70,361.69	54,887.29
1980	106	80	22	55,829.28	37,576.02
1981	120	86	26	51,851.76	31,927.13
1982	131	96	31	59,454.66	40,792.10
1983	129	92	33	54,676.74	35,773.77
1984	126	69	51	58,204.81	39,839.52
1985	114	56	54	53,269.92	36,999.01

causing a cyclical change in the population of the breeding herd of Brangus cattle under light culling (see Figure 7-8). A corollary to this observation is the cyclical alternation of high percentages of young cows and old cows in a herd under light culling already discussed in the case of Angus cattle.

As in the case of Angus cattle, the population of breeding cows is generally higher under light than under heavy culling (see Figure 7-8). Consequently, resource requirements are higher in the former case as is shown by the comparison of Tables 7-18 and 7-22, with the exception of energy supplement for reasons mentioned under scenario 2. Costs of production reported in Table 7-22 are also higher as expected, indicating that it is more expensive to raise a replacement than to keep an open cow. Comparison of Tables 7-9, 7-13, 7-19 and 7-23 shows that the cost of raising Brangus cattle under heavy culling is the highest.

Visual analysis of Figure 7-12, and comparison of Tables 7-20 and 7-24, indicate that net revenues under light culling are higher most of the time than those under heavy culling with Brangus cattle. Since raising Brangus cattle under heavy culling results in higher net revenues than raising Angus cattle under both heavy and light culling,

TABLE 7-21. SIMULATED HEIFER RETENTION RATES AND CULLED COWS IN A HERD OF BRANGUS CATTLE UNDER LIGHT CULLING.

	Production Year															
	1970	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85
Heifer Retention Rate (%)	16.0	19.0	18.0	19.0	40.0	43.0	49.0	50.0	54.0	53.0	24.0	26.0	25.0	27.0	39.0	41.0
Culled Cows[a]	24	19	21	23	52	54	53	57	60	57	26	33	34	35	51	51

[a]Culled cows include old cows, cows open in two consecutive years and cows without a calf at the end of a calving season.

TABLE 7-22. SIMULATED USE OF IMPORTANT FACTORS OF COW-CALF PRODUCTION WITH A HERD OF BRANGUS CATTLE UNDER LIGHT CULLING.

Production Year	Breeding Herd (# cows)	Land[a] (acres)	Labor (hours)	Fertilizer (metric tons)	Energy Suppl. as fed(kg)	Protein Suppl. as fed(kg)
1970	306	515.28(0.99)	1,758.68	23.39	39,609.00	6,203.00
1971	324	536.12(0.97)	1,918.90	24.33	35.355.00	9,349.00
1972	318	589.74(0.99)	2,347.88	26.77	10,900.00	10,655.00
1973	320	583.40(0.98)	2,367.56	26.48	13,466.00	10,045.00
1974	324	581.55(0.97)	2,115.84	26.39	17,287.00	9,626.00
1975	299	571.46(1.03)	1,886.35	29.94	20,048.00	8,701.00
1976	301	542.46(1.03)	1,636.88	24.62	32,467.00	7,775.00
1977	301	544.13(1.03)	1,650.52	24.70	32,982.00	7,873.00
1978	296	542.78(1.05)	844.14	24.77	34,402.00	8,062.00
1979	292	540.36(1.06)	806.28	24.52	34,063.00	8,221.00
1980	293	541.67(1.06)	951.49	24.58	32,472.00	8,218.00
1981	320	558.61(0.98)	1,081.63	25.35	29,086.00	9,311.00
1982	311	585.15(1.01)	1,156.90	26.56	16,549.00	10,001.00
1983	311	576.17(1.01)	1,119.69	26.15	19,715.00	9,573.00
1984	315	575.18(0.99)	1,058.83	26.11	21,494.00	9,264.00
1985	302	566.47(1.03)	971.01	25.71	23,135.00	9,128.00

[a]Numbers in parentheses are stocking rates in acres/head.

TABLE 7-23. SIMULATED COSTS ($) OF MAJOR FACTORS OF PRODUCTION WITH A HERD OF BRANGUS CATTLE UNDER LIGHT CULLING.

Production Year	Labor	Fertilizer	Energy Supplement	Protein Supplement	Paid Interest	Total Expenses
1970	2,884.23	1,355.60	0.00	761.73	412.61	7,405.91
1971	3,319.69	1,483.38	0.00	849.23	489.83	8,035.11
1972	4,320.09	1,685.27	645.95	1,178.06	664.32	11,736.37
1973	4,735.11	2,037.60	1,101.07	2,461.95	831.46	14,462.04
1974	4,400.95	3,297.31	1,698.95	1,801.54	939.76	15,178.54
1975	4,263.16	4,147.32	1,871.13	1,417.46	991.46	15,360.37
1976	4,043.09	3,444.75	3,111.95	1,543.67	958.08	16,411.04
1977	4,373.88	3,331.97	3,444.98	1,866.03	1,204.70	17,707.41
1978	2,397.37	3,668.41	3,603.68	1,685.27	1,107.54	16,279.29
1979	2,636.54	3,872.63	4,535.08	1,852.55	1,307.87	18,295.13
1980	2,854.47	5,233.29	5,081.62	1,936.95	1,723.34	21,531.85
1981	4,185.90	5,422.36	5,012.67	2,356.37	1,882.79	23,775.59
1982	4,442.51	5,733.00	2,656.21	2,326.10	1,915.49	21,868.56
1983	4,266.01	5,697.35	3,162.18	2,380.14	2,006.82	22,277.69
1984	4,023.54	5,739.67	3,414.68	2,218.61	1,949.33	21,840.44
1985	3,689.83	4,704.21	2,914.07	1,631.84	1,454.32	19,633.34

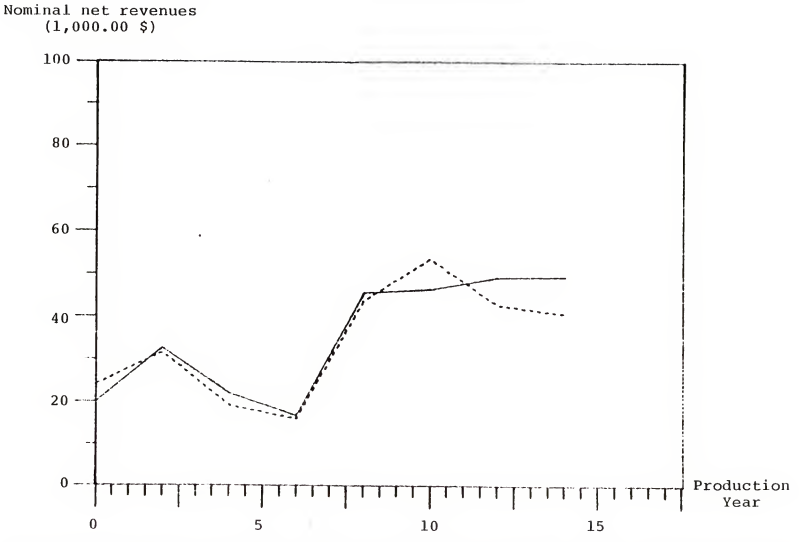


Figure 7-12. Simulated variation in nominal net revenues with Brangus cattle under light culling (solid line) and heavy culling (dotted line).

TABLE 7-24. SIMULATED SALES OF STEERS, HEIFERS AND COWS FROM A HERD OF BRANGUS CATTLE UNDER LIGHT CULLING.

Production Year	Steers (head)	Heifers (head)	Cows (head)	Total Revenue ($)	Net Revenue ($)
1970	107	89	14	27,439.32	20,033.41
1971	115	91	19	30,065.96	21,130.85
1972	138	116	21	44,445.28	32,708.91
1973	138	113	23	67,050.06	52,588.02
1974	138	84	52	37,262.52	22,083.98
1975	126	73	54	24,272.31	8,911.94
1976	114	57	53	33,127.09	16,716.05
1977	113	57	57	35,813.16	18,105.75
1978	111	52	60	61,889.86	45,610.56
1979	109	51	57	85,258.14	66,965.02
1980	108	84	26	67,901.55	46,369.70
1981	124	93	33	65,120.87	41,345.27
1982	133	100	34	71,014.94	49,146.38
1983	130	95	35	64,504.48	42,226.80
1984	134	80	51	71,267.31	49,426.88
1985	124	74	51	66,318.66	46,685.32

cow-calf production with Brangus cattle under light culling is the most profitable.

Further analysis is needed to confirm the above assertion. It involves the notion of stochastic dominance used in economic analyses of risky prospects.

Interpretation of Simulated Net Returns As Risky Prospects

The notion of stochastic dominance has been developed to simplify the choice between uncertain prospects (Hammond, 1974). For instance, the hypothetical manager mentioned earlier who is faced with the choice between Angus and Brangus breeds can use the stochastic dominance technique and rules to determine the breed whose corresponding net returns as uncertain prospects are randomly dominant over time. The basis for stochastic dominance rules is the preference assumption discussed below.

In the first-degree stochastic dominance, it is presumed that all decision makers prefer more to less. In the present case the hypothetical cow-calf producer prefers more net revenues to less net revenues. To explain and illustrate the ordering rule of the first degree stochastic dominance, let us consider Figure 7-13, which shows inflated net revenues ordered from the lowest to the highest values observed under two sets of management strategies. Set one

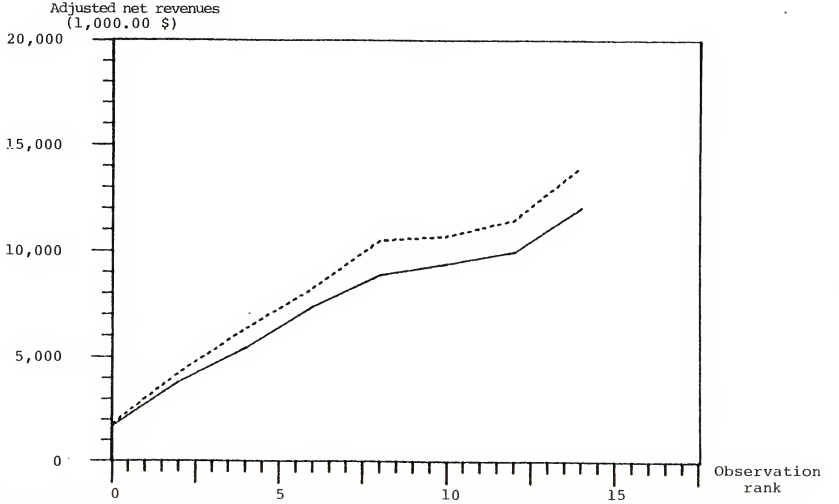


Figure 7-13. Ordered adjusted net revenues with Brangus cattle under heavy culling (dotted line) and Angus cattle under heavy culling (solid line).

is the combination of Brangus cattle and heavy culling while set two consists of Angus Cattle and heavy culling. According to the ordering rule, set one dominates set two by first-degree stochastic dominance because its curve lies consistently to the left of the curve corresponding to set two.

In many instances, the two curves cross at least once, violating the ordering rule of the first-degree stochastic dominance. In such cases, second-degree and/or third-degree stochastic dominances are considered. The second-degree stochastic dominance uses the assumption that, in the present case study, successive amounts of net revenue have diminishing value for the cow-calf operator. The third-degree stochastic dominance implies that decision makers become decreasingly averse to risk as they become wealthier. (Anderson, 1974). Details of second and third degree stochastic dominance are not covered here because it is not in the scope of this study to do so. The primary reason for including the above notions in the first test of the model is to demonstrate that UF COW-CALF can be a valuable research tool for agricultural economists.

It still remains to show systematically that using Brangus cattle under light culling in a cow-calf operation

in North Florida is the most profitable. The first-degree stochastic dominance was applied to the question.

In order to validly compare net revenues obtained under various sets of management strategies defined earlier, they were adjusted by the 1985 farm price index of 261.35 based on the 1967 dollar value. Such an operation was necessary to convert all net revenues to the same dollar value. The adjusted revenues were then ordered from the lowest to the highest values estimated under different sets of management strategies. Six comparisons were made on the basis of Figures 7-13, 7-14, 7-15, 7-16, 7-17 and 7-18. Figure 7-13 used in earlier demonstrations constitutes the basis for comparison one. Its close examination indicates that management strategy consisting of raising Brangus under heavy culling dominates raising Angus cattle under the same culling policy and other common points mentioned earlier.

Comparison two between Brangus cattle under heavy culling and Brangus cattle under light culling, is illustrated in Figure 7-14. According to Figure 7-14, the ordering rule of first-degree stochastic dominance is violated. However, by comparing Tables 7-20 and Figure 7-12, one can conclude that raising Brangus cattle under light culling is more profitable than under heavy culling in North Florida.

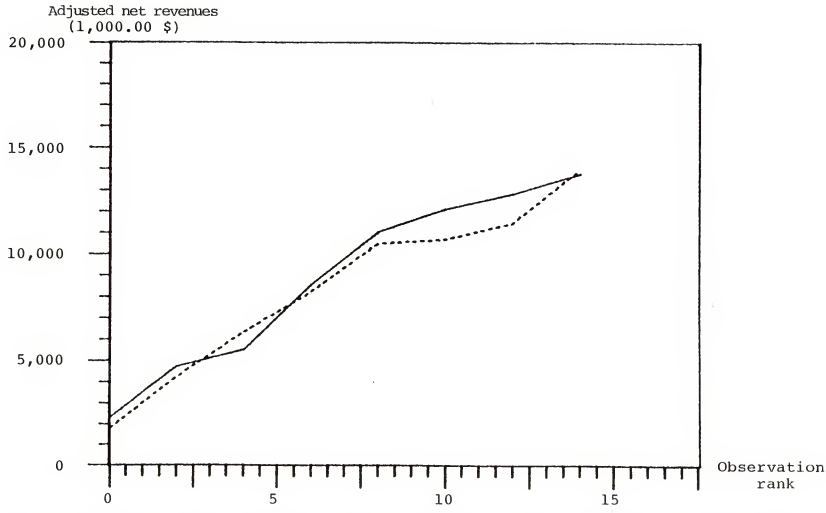


Figure 7-14. Ordered adjusted net revenues with Brangus cattle under light culling (solid line) and heavy culling (dotted line).

Figure 7-15 is an illustration of comparison three which involves Angus breed under heavy and light culling. The ordering rule of the first-degree stochastic dominance is also violated. Comparisons two and three tend to indicate that, within the same breed, net revenues generated under light culling are not appreciably different from those generated under heavy culling.

Comparison four is described in Figure 7-16. According to Figure 7-16, net revenues generated by raising Brangus cattle under light culling dominates those obtained with Angus cattle under the same culling policy. From comparison four and Figure 7-13, one can conclude that under the same culling policy higher net revenues are associated with Brangus cattle while lower revenues correspond to Angus cattle.

In comparison five, inflated net revenues generated with Brangus cattle under heavy culling are contrasted with those obtained with Angus cattle under light culling. The ordering rule of first-degree stochastic dominance is violated in this case as well (see Figure 7-17). However a close examination of Tables 7-14 and 7-20 indicates that net revenues are generally higher with Brangus under heavy culling than with Angus cattle under light culling.

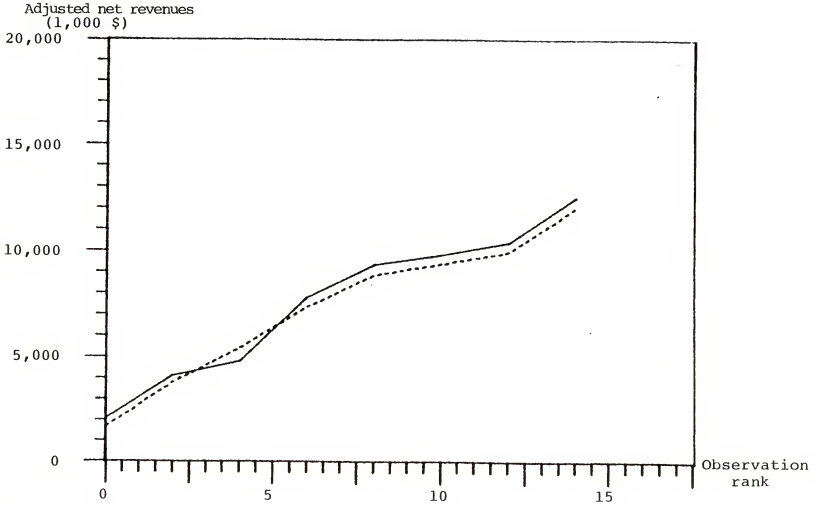


Figure 7-15. Ordered adjusted net revenues with Angus cattle under light culling (solid line) and heavy culling (dotted line).

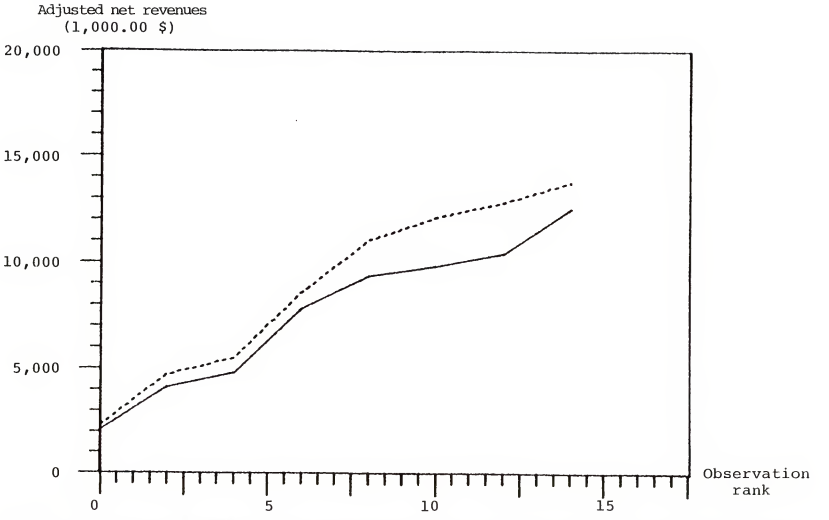


Figure 7-16. Ordered adjusted net revenues with Brangus cattle under light culling (dotted line) and Angus cattle under light culling (solid line).

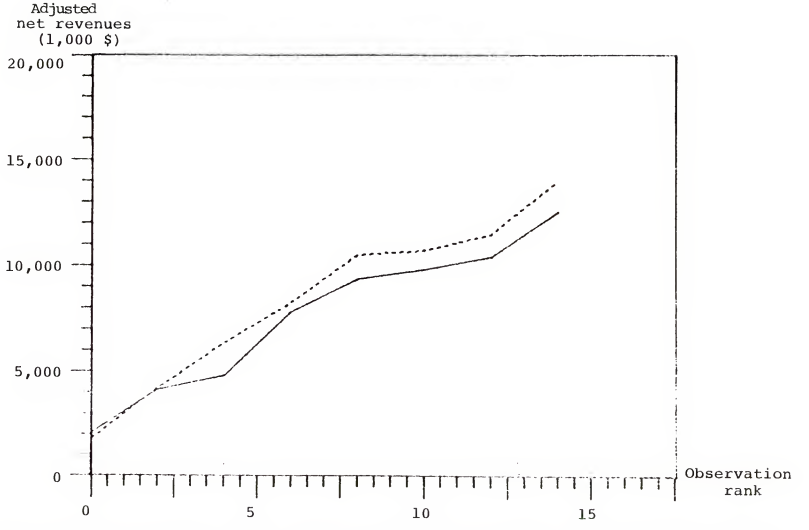


Figure 7-17. Ordered adjusted net revenues with Brangus cattle under heavy culling (dotted line) and Angus cattle under light culling (solid line).

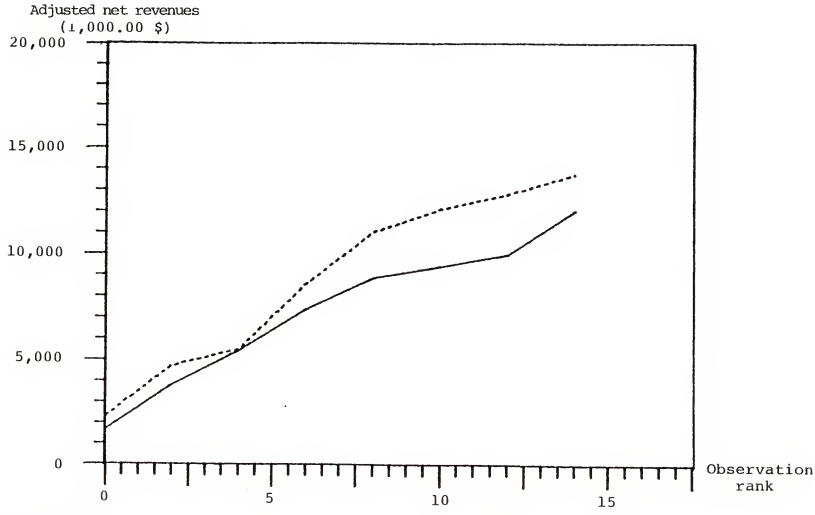


Figure 7-18. Ordered adjusted net revenues with a Brangus herd under light culling (dotted line) and Angus herd under heavy culling (solid line).

The last comparison is illustrated in Figure 7-18. It involves a Brangus herd under light culling and an Angus herd under heavy culling. The ordering rule of first-degree stochastic dominance is satisfied in this case, indicating that generally net revenues generated with a herd of Brangus cattle under light culling are higher than those pertaining to Angus cattle under heavy culling.

It can be concluded from comparisons one, four, five and six that the hypothetical cow-calf producer in North Florida would favor Brangus cattle over Angus cattle since the former are likely to generate higher net revenues than the latter. The choice of culling policy within the Brangus breed is not so clear since the net revenues seem of equal magnitude. However, a re-examination of Figure 7-14 and the higher costs of production associated with heavy culling show that raising Brangus cattle under light culling is the best management combination in North Florida.

Concluding Comments

The primary assessment of the validity of simulated results should consist of making certain that input data reflect the realities of the system under study. The secondary level of validation of the simulation model must be an inquiry about the consistency between simulated

results and input data, especially in the case of a deterministic model such as UF COW-CALF. Complete validation requires comparing current simulated results to others obtained from the same study but using different methods and procedures. This subsection describes a brief, three-step evaluation of simulated herd dynamics, growth and nutritional requirements, and economics of cow-calf production under already defined conditions and management strategies.

The parameters of herd dynamics presented in Table 6-5 are estimated from experimental data analyzed by indicated sources. Estimates of pregnancy rates by Boyd (1976) show a slight advantage of Brangus over Angus cattle due to heterosis effect. This trend was demonstrated by Cundiff (1970), Peacock et al. (1976), and Peacock and Koger (1982). Simulated pregnancy rates reported in Tables 7-2 and 7-16 follow the same trend and are within the same realistic range. The slight variation within the same cow age over several years of production is due solely to truncation error. The current magnitude of such variation should not compromise the validity of these results since, in reality, one does not expect cow pregnancy rate within a cow age class to be exactly the same in successive production years.

Analysis by Boyd (1976) and Restle (1983) of the same experimental data generated under Florida conditions showed

higher calf mortality rate with Brangus than with Angus cattle (see Table 6-5). Consequently, Angus cattle are associated with higher calf survival rate as, supported by a report by Cunha et al. (1973). Simulated calf survival rates reported in Tables 7-1 and 7-15 are within a realistic range and show a 2 percent advantage for Angus over Brangus cattle, on the average.

As explained earlier, the two culling policies implemented by the UF COW-CALF affect herd composition differently. Simpson et al. (1984) analyzed the effects of heavy and light culling on beef production under the assumption that heifers are bred for the first time at two years of age. Their conclusion was that fewer calves were sold under heavy culling than under light culling because of a greater need for replacement heifers. The same conclusion was reached while simulating the effects of culling policy on herd dynamics with UF COW-CALF (see Tables 7-10 and 7-14).

Simulated growth patterns of Angus and Brangus cattle are consistent with data presented in Table (6-4). Under optimal feeding conditions, female Brangus cattle reached the pubertal weight of 273.74 kg at the physiological age of 252 days according to UF COW-CALF. Corresponding figures for Angus heifers were 226.82 kg and 247 days. Data in

Table 7-17 indicate that female Brangus cattle grow faster than Angus cattle, agreeing with reports by Boyd (1976), Stewart (1977), and Restle (1983). Those results explain earlier reports that the two breeds reached mature weight at the same chronological age of five years under the same conditions, even though Brangus cattle were heavier than Angus cattle at maturity (see Figure 7-11).

Expressions (7-2) and (7-6) describing postpubertal growth patterns of Angus and Brangus cattle, respectively, with degree of fatness explained in Chapter III, also reflect data presented in Table 6-4. However, equations (7-2) and (7-6) are different from other cattle growth equations (see Table 7-25). Equation (7-6) differs from that of Melton even though the constants are estimated from the same experimental data. The former is a literal numerical application of the Brody model by use of distinct pubertal weight and age. Melton's equation is the result of a non-linear regression of body weight against age without specifying the coordinates of the inflection point, i.e., puberty. However, Figure 7-19 shows some agreement between the two systems of estimation when comparing mature phase of current growth according to UF COW-CALF and mature phase of historical growth according to Melton's equation. A visual analysis of Figure 7-19 leads to the conclusion that the two

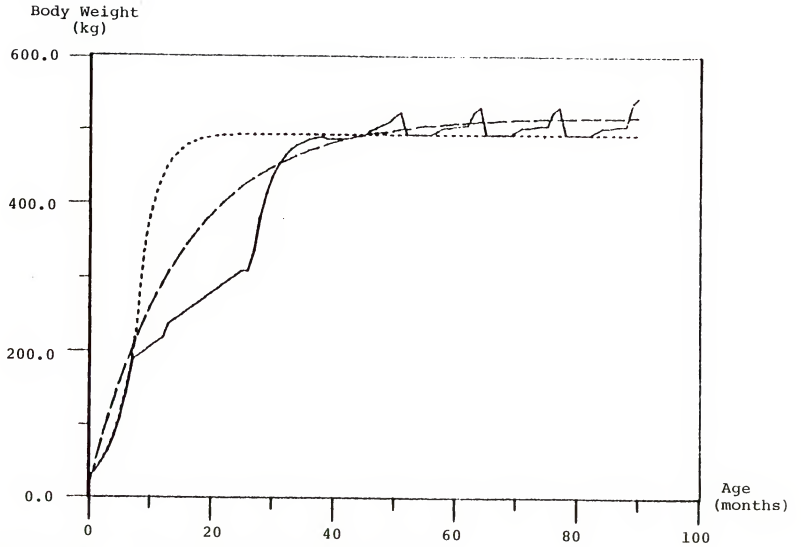


Figure 7-19. Comparative growth curves of Brangus cattle.

Melton's growth curve (dashed line) and UF COW-CALF's theoretical (dotted line) and current growth (solid line) of Brangus cattle in North Florida.

TABLE 7-25. COMPARATIVE TABLE OF EQUATIONS DESCRIBING POSTPUBERTAL GROWTHS OF ANGUS AND BRANGUS CATTLE.

Source of Equation	Breed	
	Angus	Brangus
UF COW-CALF	$W_t = 425.1 - 198e^{-0.008t}$	$W_t = 493.75 - 220.01e^{-0.009t}$
Wong (1974)	$W_t = 410.43 - 388.58e^{-0.0064t}$	NA
Melton (1979)	NA	$W_t = 518.06 - 500.26e^{-0.0022t}$

NA: not available. W_t and t are as explained in Chapter III.

systems indicate approximately the same degree of fatness in the mature phase of growth. It is also interesting to notice that the two curves intersect at the inflection point. The above conclusion must be true since the two studies involved the same environmental and nutritional conditions. Thus, the growth model of UF COW-CALF appears to be a valid one.

Wong (1974) described historical growth of Angus cattle using experimental data from USDA Brooksville Beef Cattle Research Station in Florida. A non-linear regression of body weight against age, based on Brody's model resulted in the equation presented in Table 7-25. A comparison of that equation with expression (7-2) shows different constants. These differences are expressed in Figure 7-20 and can be appreciated by comparing historical growth according to Wong's equation with theoretical and current growth according to the UF COW-CALF model. Two reasons can be cited for those differences:

1) even though the same breed was involved, the animals were in two distant locations and under different nutritional conditions;

2) it was assumed that the experimental animals in Brooksville grew according to the same pattern from birth to maturity instead of two as suggested by Brody.

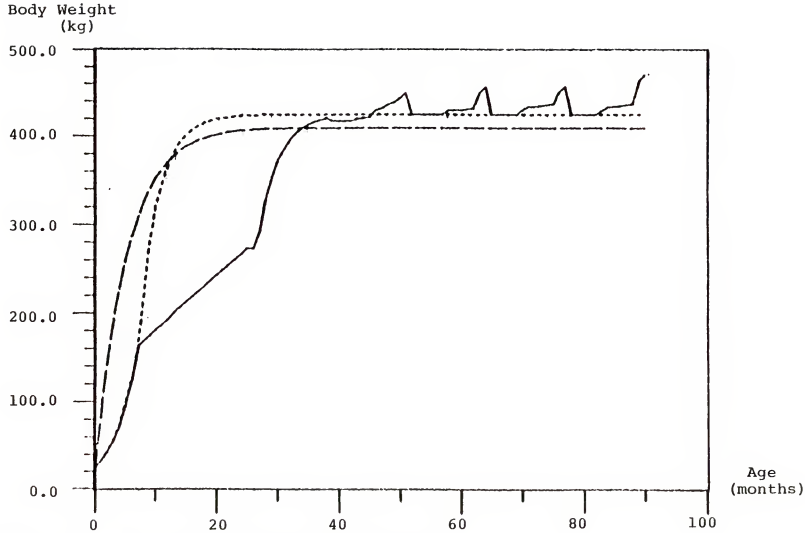


Figure 7-20. Comparative growth curves of Angus calttle.

Wong's growth curve in Central Florida (dashed line) and UF COW-CALF's theoretical (dotted line) and current (solid line) growth in North Florida.

Use of the numerical and regression methods to determine the coefficients of the growth model from the same experimental data gave approximately the same results in the mature phase of the growth curve. One can deduce from the above observation that the two methods can be validly used to describe growth curves. The regression method is appropriate for describing historical growth of animals while the numerical method is suitable for predicting growth response to presently prevailing environmental and nutritional conditions. The numerical method is therefore appropriate for simulation of animal growth and nutritional requirements. Use of a growth equation, based on regression method without distinction of the inflection point, to determine energy requirements will overestimate NE_m and underestimate NE_g in the prepubertal phase of growth. It will also result in incorrect NE_g in the mature phase of growth since it does not address the fact that weight gain in that stage is due solely to fat accumulation.

Estimates of net energy requirements by UF COW-CALF are close to those of NRC (1976, 1978 and 1984). According to NRC (1984), a medium-frame heifer calf weighing 150.0 kg and gaining 1.0 kg daily requires a NE_m of 3.30 Mcal/day and a NE_g of 2.94 Mcal/day. Corresponding values of NE_m and NE_g estimated according to UF COW-CALF for a Brangus heifer

weighing 163.34 kg and gaining 1.28 kg/day are 3.68 Mcal/day and 3.84 Mcal/day, respectively (see Table 7-17).

Requirements for crude protein estimated with the use of UF COW-CALF are close to those of NRC (1976 and 1978) but lower than the estimations of NRC (1984). The difference is due mainly to the magnitude of protein digestibility and biological value used in NRC (1984).

Previous studies of culling policy tend to favor heavy culling contrary to earlier conclusions that suggested preference of light culling. Melton and Olson (1979) showed that a combination of selective retention of replacement heifers with heavy culling resulted in higher net revenues than light culling. This finding is in agreement with the conclusion of Koger and Hargrove (1983) that the weight of beef sold from the combination of selective retention of replacement heifers with heavy culling exceeded by 2.2 percent the amount of beef sold when replacing culled cows with randomly retained weaned heifers.

The discrepancy between the conclusions reached under the present and previous studies of culling policy is due mainly to the applications of selective versus random retentions of replacement heifers. The combination of selective retention of weaned heifers and heavy culling is likely to improve the reproductive performance of a herd in

the long run (Clarke et al, 1984; Koger, 1976), thus reducing the numbers of culled cows and retained heifers and ultimately eliminating additional costs of replacement recognized under the present study and by Simpson et al. (1984) and Melton and Olson (1979). In conclusion, the results of the study of culling policy by means of UF COW-CALF can be regarded as plausible.

CHAPTER VIII

SUMMARY AND CONCLUSION

The Florida beef cattle industry has evolved from stock of the Criollo breed before the twentieth century to the diversified genetic pool of the present day (Phillips, R.W., 1963). Prior to the twentieth century, the Florida beef cattle industry was in an undeveloped state marked by cattle fever tick and other parasites, poor pastures, inadequate nutrition, diseases and lack of systematic management (Cunha, 1976). Progressive upgrading of Criollo cattle with Brahman and European breeds, combined with improved feeding and other management practices, transformed the Florida cattle industry from its poor condition to its economically and technologically viable current state.

Even though the Florida beef cattle industry has prospered substantially in the twentieth century, inability to produce high energy feeds locally necessitated the outshipment of weaned calves to other states for finishing. The energy crisis of recent years compromised the economic efficiency of sending Florida cattle to distant feedlots and dictated the establishment of slaughter houses in Florida.

The latter effort was hampered by the ever present problem of feed supply and, furthermore, by the declining cattle prices of the 1980's. The above impediments, added to the vagaries of weather and the complexity of the world market, required a new remedy to assist the Florida beef cattle industry to adjust to its new realities. It was believed that systems analysis could play a positive role in that remedy.

A mathematical model of a cow-calf production system, conceived to include the characteristics of the Florida beef cattle industry, was developed and implemented by a computer program written in Fortran and named UF COW-CALF. This program was designed to allow systematic study of various beef cattle management practices in general and culling policy and breed selection in particular. It was partitioned into two categories of subroutines. Category I subroutines pertain to herd dynamics as influenced by breed, reproduction, mortality, culling policy, retention of weaned heifers and marketing strategy. Incorporated culling policies are based on old age, infertility and calf loss. Marketing strategies include immediate sale or backgrounding of weaned calves and scheduling sales of culled cows. Systematic replacement of all culled cows with available

weaned heifers or limiting retention of weaned heifers at preselected rates can also be implemented.

Subroutines in category II pertain to behavioral study of the following attributes of an average animal of specified sex, age, physiological state and breed, under specified nutritional and environmental conditions: growth, lactation, requirements for net energy, crude protein, forage, energy and protein supplements. Nutritional requirements of the entire herd are computed by scaling those of an average animal according to the number of individuals in various age and functional classes. Other factors of production, such as land and fertilizer, are then estimated based on herd forage requirements and pasture dry matter yield. Average annual production cost and net return are computed in final simulation activities. The University of Florida's cow-calf model can simulate production over several years while updating it on a monthly basis.

A study of culling policy and breed effects on herd dynamics and net return in North Florida was conducted by the use of UF COW-CALF in an effort to test its reliability as a research and management tool. The breeds of cattle involved were Angus and Brangus. Two systems of culling were considered. Heavy culling consisted of eliminating all cows without a calf at the end of calving season, cows open

at weaning and those which reached culling age fixed at ten years. Light culling included removal of old cows, cows open in two consecutive breeding seasons and those which lost their calves at parturition. All culled cows were replaced with available weaned heifers retained at random. Weaning was fixed at the nominal age of seven months. Experimental data used were from the University of Florida Beef Research Unit. Data on growth and reproductive performances reflected breed adaption to prevailing nuritional and enviromental conditions. Data on forage production represented commercial pasture conditions in North Florida. Fifteen years of production extending from 1970 to 1985 were simulated. Nominal costs of major factors of production and prices of calves and cows corresponding to that period were used.

Four scenarios resulting from combinations of the two breeds and culling policies were studied. Scenario I was a study of Angus cattle under heavy culling. Results of this study indicated that under heavy culling, the herd remained relatively young as a consequence of retaining many weaned heifers and culling many mature cows each year. Fewer calves were available for sale. Simulated growth showed that under North Florida conditions, female Angus cattle reached maturity at the chronological age of five years

after their specific growth rate was restricted to no more than 0.2 kg/day between weaning and the age of two years. Energy supplement was mostly required by growing animals between weaning and the age of two. Protein supplement was required by all weaned and old animals in August, September and November, corresponding to low concentrations of protein in available forage. Nutrient requirements are close to those reported by NRC (1976 and 1978), supporting the reliability of UF COW-CALF as a predictive tool. Study of scenario one also showed that the breeding herd of Angus cattle under heavy culling and at the equilibrium size of 302 cows required 446 acres of pasture producing 272.15 kg of forage dry matter per acre in May, with total forage dry matter consumed by the herd representing 45 percent of the total forage dry matter available in the same month. Total production cost remained generally high due to high costs of raising replacement heifers. Total net revenues remained generally satisfactory, probably due to the omission management and land charges.

Scenario II consisted of studying Angus cattle under light culling. High percentages of young and old cows alternated cyclically in this case. More calves were sold as a consequence of retaining open cows which were likely to conceive the next breeding season. Herd size remained

generally higher under light culling than under heavy culling since, in the former case, less cows were culled. Consequently 8 percent more land was required under light than heavy cullings. However total yearly production cost was 7 percent higher under heavy culling than light culling because of additional cost of raising replacement heifers in the former case. Thus, light culling was likely to generate more net revenues than heavy culling.

A herd of Brangus cattle under heavy culling was studied in scenario III. Herd dynamics parameters such as mortality and pregnancy rates were in agreement with input data which showed lower calf survival rate and higher pregnancy rate for Brangus than Angus cattle. These results further indicated that computations by UF COW-CALF were correct. Approximately 12 percent more Angus than Brangus calves were sold under heavy culling. As in the case of Angus cattle, culled Brangus cows constituted a high percentage of animals sold under heavy culling.

Brangus cattle grew faster than Angus cattle. Consequently, Brangus cows reached mature weight of 493.75 kg (425.1 kg for Angus cows) at the same chronological age of five years as Angus cows under the same nutritional conditions. Higher nutritional requirements were associated with Brangus cattle as expected. Raising Brangus cattle

required higher levels of resources than Angus cattle under heavy culling. Brangus cattle raised on a North Florida pasture with a dry mater yield of 272.15 kg/acre in May needed 13 percent more land than Angus cattle under heavy culling and feed supplementation. Total costs of production were 13 percent higher with Brangus cattle than with Angus under heavy culling. Nevertheless, net revenues generated under the same conditions were generally 17 percent higher with Brangus than Angus cattle; the reason was that Brangus cattle were sold at heavier weights than their Angus counterparts. Weaning weights of Brangus and Angus calves were 199.07 kg and 187.48 kg, respectively.

Approximately 40 percent more Angus calves were sold under light culling than Brangus calves under heavy culling. Angus cattle under light culling required 9 percent less land than Brangus cattle under heavy culling because more growing heifers were present in the former case. Average annual cost of raising Brangus cattle under heavy culling were 20 percent higher than of Angus cattle under light culling. Average annual return associated with Brangus under heavy culling was 13 percent higher than that obtained with Angus cattle under light culling.

The study of Brangus cattle under light culling was the basis for scenario IV. The results of this study confirmed

that heavy culling necessitated more use of factors of production and consequently more expense with both Angus and Brangus breeds. Brangus cattle were generally more expensive to raise than Angus cattle under both light and heavy cullings. However, Brangus cattle were likely to generate higher net return than Angus cattle. Light culling caused cyclical alternation of high percentages of young and old cows in the herd of Brangus cattle also. Twenty-eight percent more Brangus calves were sold annually under light than heavy culling, while 24 percent fewer Brangus calves were available for sale under heavy culling. Almost equal numbers of Angus and Brangus cows were culled annually under the same culling policy. Brangus cattle required 4 percent more land under light than heavy cullings. In general, Brangus cattle required 13 percent more land annually than Angus cattle. In terms of production cost, scenario three was the most expensive, followed by scenarios four, one and two, in that order. However, scenario four is the most profitable, preceding scenarios three, two and one, respectively.

In conclusion, UF COW-CALF is considered a reliable tool for research and management. Raising Brangus cattle in North Florida requires greater production cost but is more profitable than raising Angus cattle. Heavy culling

contributes to higher expenses and is less profitable than light culling without reproductive improvement over time.

APPENDIX

Figure A-1. Flowchart of logical concepts related to growth and nutritional requirements of calves.

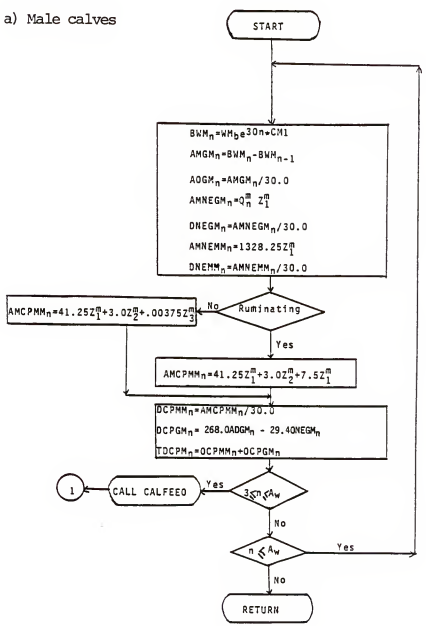
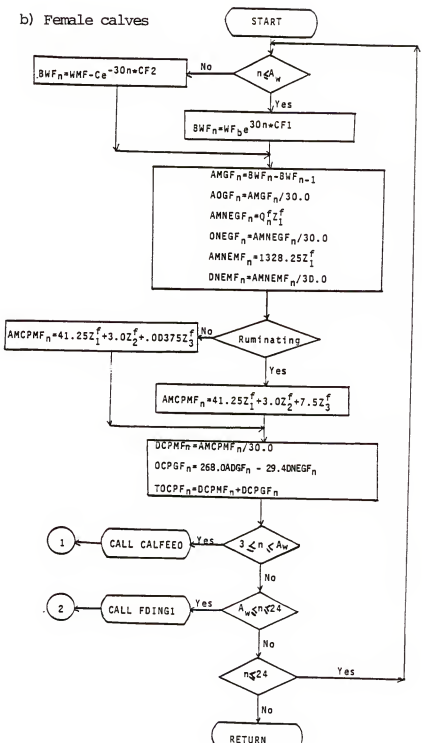


Figure A-1 - continued.

b) Female calves



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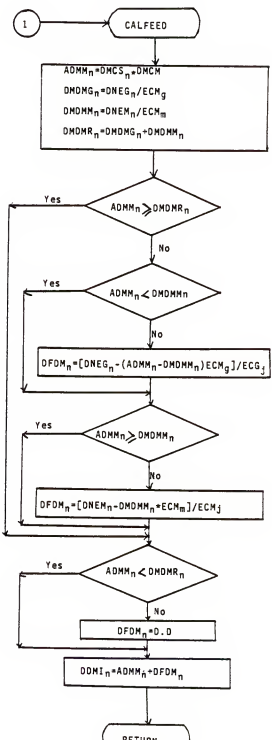

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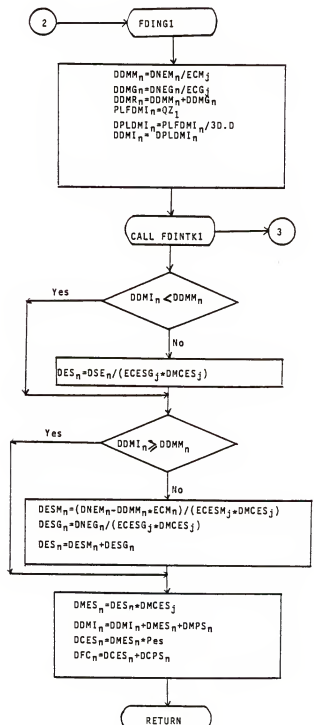

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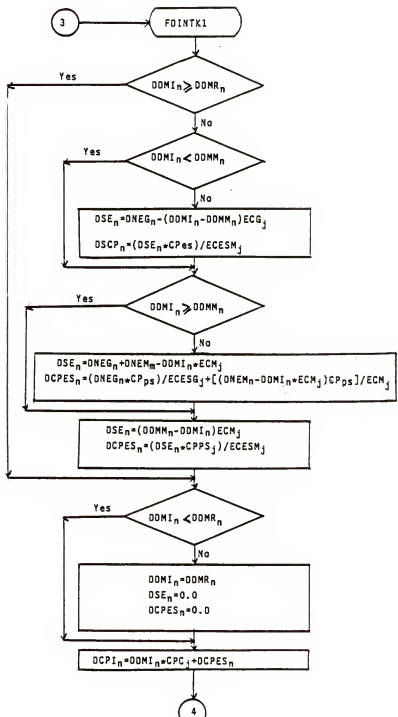

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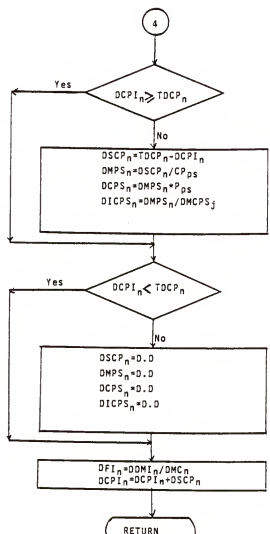

Refer to Table A-1 for explanation of symbols.

TABLE A-1. GLOSSARY OF SYMBOLS USED IN FIGURE A-1.

$ADGF_n$:	Female average daily gain at the age of n months.
$ADGM_n$:	Male average daily gain at the age on n months.
$ADMM_n$:	Daily milk dry matter available to a calf of n months of age.
$AMCPMF_n$:	Average monthly crude protein requirement for maintenance of a female calf of n months of age.
$AMCPMM_n$:	Average monthly crude protein requirement for maintenance of a male calf of n months of age.
$AMGF_n$:	Average monthly gain of a female calf of n months of age.
$AMGM_n$:	Average monthly gain of a male calf of n months of age.
$AMNEGF_n$:	Average monthly net energy requirement for gain of a female calf of n months of age.
$AMNEGM_n$:	Average monthly net energy requirement for gain of a male calf of n months of age.
BWF_n:	Body weight of a female calf of n months of age.
BWM_n:	Body weight of a male calf of n months of age.
$C = WMF - W_p$	
CF_1:	Female calf relative growth rate at the prepubertal phase of growth (K_1 in Brody's model).
CF_2:	Female calf relative growth rate at the prepubertal phase of growth (K_2 in Brody's model).
CM_1:	Male calf relative growth rate at the prepubertal phase of growth (K_1 in Brody's model).
CPC_j:	Crude Protein concentration (% DM) of forage in jth month of the year.
$CPES_j$:	Concentration (% DM) of crude protein in energy supplement in jth month of the year.

Table A-1 - continued

$CPPS_j$: Concentration (% DM) of crude protein in protein supplement in jth month of the year.

$DCES_n$: Daily cost of energy supplement for a calf of n months of age.

$DCPES_n$: Daily crude protein from energy supplement available to a calf of n months of age.

$DCPGF_n$: Daily crude protein requirement for gain of a female calf of n months of age.

$DCPGM_n$: Daily crude protein requirement for gain of a male calf of n months of age.

$DCPI_n$: Daily crude protein intake of a calf of n months of age.

$DCPMF_n$: Daily crude protein requirement for maintenance of a female calf of n months of age.

$DCPMM_n$: Daily crude protein requirement for maintenance of a male calf of n months of age.

$DCPS_n$: Daily cost of protein supplement for a calf of n months of age.

$DDMG_n$: Daily forage dry matter requirement for gain of a calf of n months of age.

$DDMI_n$: Daily dry matter intake for a calf of n months of age.

$DDMM_n$: Daily forage dry matter requirement for maintenance of a calf of n months of age.

$DDMR_n$: Daily forage dry matter requirement for a calf of n months of age.

DES_n: Daily energy supplement (as fed) requirement for a calf of n months of age.

$DESG_n$: Daily energy supplement (as fed) requirement for gain of a calf of n months of age.

Table A-1 - continued

$DESM_n$: Daily energy supplement (as fed) requirement for maintenance of a calf of n months of age.

DFC_n: Daily cost of feed supplement for a calf of n months of age.

$DFDM_n$: Daily forage dry matter requirement for a calf of n months of age.

$DICPS_n$: Daily intake of protein supplement (as fed) by a calf of n months of age.

$DMCES_j$: Concentration of dry matter (%) in energy supplement at jth month of the year.

DMCM: Milk dry matter content (%).

$DMCS_n$: Daily milk consumption by a calf of n months of age.

$DMDMG_n$: Daily milk dry matter required for gain by a suckling calf of n months of age.

$DMDMM_n$: Daily milk dry matter required for maintenance of a suckling calf of n months of age.

$DMDMR_n$: Daily milk dry matter required by a suckling calf of n months of age.

$DMPS_n$: Intake of dry matter from protein supplement by a suckling calf of n months of age.

$DNEGF_n$: Daily net energy requirement for gain by a female suckling calf of n months of age.

$DNEGM_n$: Daily net energy requirement for gain by a male suckling calf of n months of age.

$DNEMF_n$: Daily net energy requirement for maintenance of a female suckling calf of n months of age.

$DNEMM_n$: Daily net energy requirement for maintenance of a male suckling calf of n months of age.

Table A-1 - continued

$DPLDMI_n$: Daily physical limit of forage dry matter intake by a calf of n months of age.

$DSCP_n$: Daily supplemental crude protein requirement for a calf of n months of age.

DSE_n Daily supplemented net energy for a calf of n months of age.

$ECESG_j$: Concentration of net energy (% DM) available for gain in energy supplement at jth month of the year.

$ECESM_j$: Concentration of net energy (% DM) available for maintenence in energy supplement at jth month of the year.

ECG_j: Concentration of net energy (% DM) available for gain in forage at jth month of the year.

ECM_g: Concentration of net energy (% DM) available for gain in milk.

ECM_j: Concentration of net energy (% DM) available for maintenance in forage at jth month of the year.

ECM_m: Concentration of net energy (% DM) available for maintenance in milk.

J: Designates month of the year (J = 1, 2, ... 12, corresponding to January, February, ..., December).

n: Age in months.

P_{es}: Price ($/kg DM) of energy supplement.

$PLFDMI_n$: Physical limit of forage dry matter intake of a calf of n months of age.

P_{ps}: Price ($/kg DM) of protein supplement.

Q: Generally used to designate constant terms of an equation.

$Q = 15(0.1493ECM_j - 0.046ECM_j^2)$

Table A-1 - continued.

$Q_n = 15(56.03ADGF_n + 12.62ADGF_n^2)$

$Q_n = 15(52.75ADGM_n + 6.84ADGM_n^2)$

$TDCPF_n$: Total daily crude protein requirement of a female of n months of age.

$TDCPM_n$: Total daily crude protein requirement of a male of n months of age.

W: Body weight in general.

WF_b: Female birth weight.

WF_p: Female weight at puberty.

WM_b: Male birth weight.

WMF: Female mature weight.

$z_1 = (W_n^{0.75} + W_{n-1}^{0.75})$

$z_1^f = (BWF_n^{0.75} + BWF_{n-1}^{0.75})$

$z_2^f = (BWF_n^{0.6} + BWF_{n-1}^{0.6})$

$z_3^f = (BWF_n + BWF_{n-1})$

$z_1^m = (BWM_n^{0.75} + BWM_{n-1}^{0.75})$

$z_2^m = (BWM_n^{0.6} + BWM_{n-1}^{0.6})$

$z_3^m = (BWM_n + BWM_{n-1})$

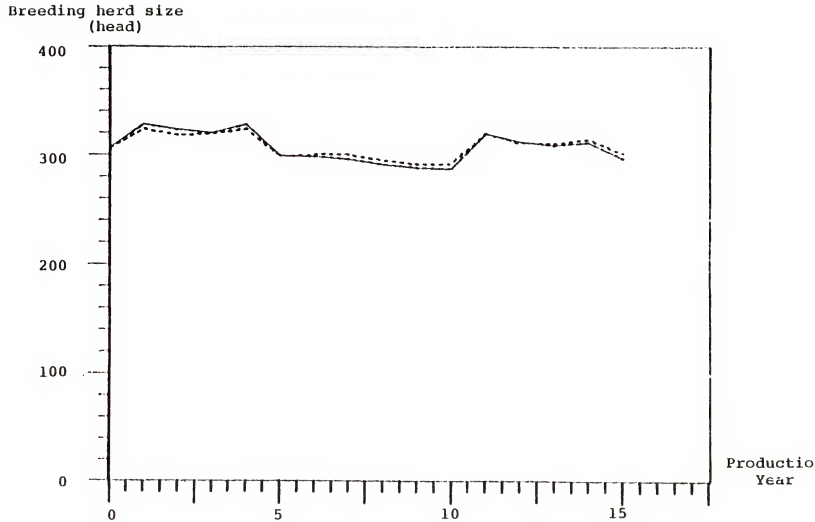

Figure A-2. Simulated variation in the population of breeding Angus cows (solid line) and Brangus cows (dotted line) under light culling in North Florida.

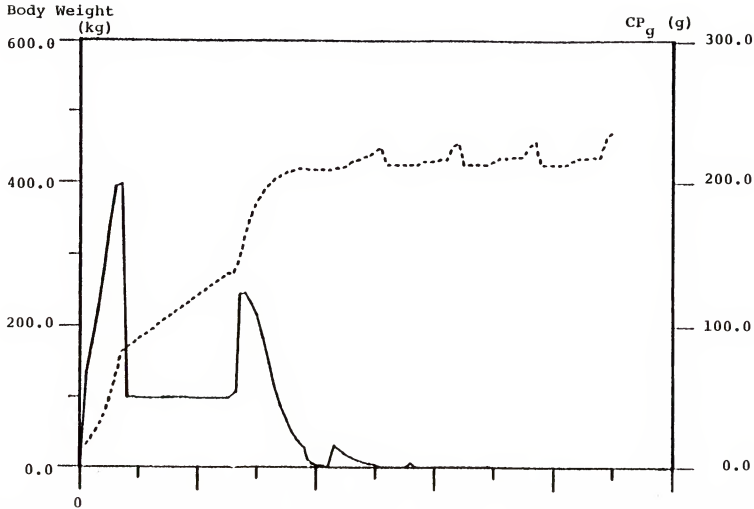

Figure A-3. Simulated variation in CP_g (solid line) in relation to simulated current body weight change (dotted line) of Brangus cattle in North Florida.

TABLE A-2. SIMULATED VARIATION IN BREEDING HERD COMPOSITION(%) BY AGE CLASS IN A HERD OF ANGUS CATTLE UNDER HEAVY CULLING IN NORTH FLORIDA

Production year	Cow age (years)							
	2	3	4	5	6	7	8	9
1970	25	23	20	18	14	0	0	0
1971	23	19	17	15	14	12	0	0
1972	14	20	16	14	13	13	10	0
1973	18	11	15	12	12	11	11	9
1974	20	15	9	13	11	11	10	10
1975	28	17	13	8	12	11	11	9
1976	26	14	13	10	7	10	9	9
1977	27	20	11	10	9	6	9	8
1978	24	21	16	9	9	8	5	8
1979	27	19	16	12	8	8	7	4
1980	26	20	14	12	11	6	7	5
1981	25	19	15	11	10	9	5	5
1982	23	20	15	12	10	9	8	4
1983	24	17	14	11	10	8	8	6
1984	24	19	14	11	10	9	7	6
1985	24	19	15	11	10	9	7	5

TABLE A-3. SIMULATED VARIATION IN BREEDING HERD COMPOSITION(%) BY AGE CLASS IN A HERD OF ANGUS CATTLE UNDER LIGHT CULLING IN NORTH FLORIDA

Production year	Cow age (years)							
	2	3	4	5	6	7	8	9
1970	25	23	10	18	14	0	0	0
1971	21	20	19	16	14	13	0	0
1972	3	21	19	18	15	13	11	0
1973	4	3	21	18	17	14	13	11
1974	6	4	3	21	19	18	15	14
1975	8	7	5	3	22	20	19	16
1976	20	7	6	5	3	21	19	17
1977	22	20	7	6	5	3	20	17
1978	22	21	19	7	6	4	3	17
1979	24	21	20	18	7	5	4	2
1980	21	19	17	16	14	5	4	3
1981	18	18	16	14	13	13	5	3
1982	8	18	17	15	14	13	12	4
1983	10	8	16	15	14	13	12	11
1984	12	10	8	16	15	14	13	12
1985	14	13	10	8	16	15	14	12

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BIOGRAPHICAL SKETCH

Beramgoto Tarounga was born March 31, 1948, in Moundou, Chad, Central Africa. He entered the Franciscan Seminary in the small town of Donia in 1965, and continued in the Jesuit Seminary in the city of Sarh until June, 1972. In October of the same year he renounced his ambition for priesthood and enrolled in the Institut des Sciences at the Universite du Tchad, from which he received the Diplome Universitaire d' Etude Scientifique, Natural Sciences section, in June 1975. He entered Tuskegee Institute, Alabama, in September, 1976, from which he graduated with the degree of Bachelor of Science in animal and poultry sciences in December, 1978. In September, 1979, he was accepted to the Graduate School of the University of Florida, from which he obtained the Master of Science degree in animal science (ruminant nutrition) with minor in food and resource economics in March, 1981. He was awarded the degree of Master of Agricultural Management and Resource Development in food and resource economics in December, 1982, by the same school. He is a candidate for the degree of Doctor of Philosophy, specializing in analysis of beef cattle production systems and breeding at the University of Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Timothy A. Olson, Chairman
Assistant Professor of Animal Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Glen H. Smerage, Cochairman
Associate Professor of Agricultural Engineering

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